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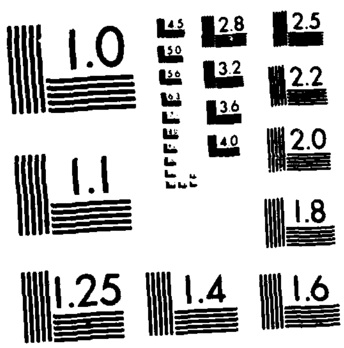

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AN EVALUATION OF THE PAVEMENT CONDITION INDEX PREDICTION MODEL FOR FLEXIBLE AIRFIELD PAVEMENTS

James D. Lyon, Captain, USAF

LSSR 11-83

DEPARTMENT OF THE AIR FORCE

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Wright-Patterson Air Force Base, Ohio

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The U.S. Army Construction Engineering Research Laboratory (CERL) is in the process of developing a comprehensive pavements maintenance management system for the Air Force. A major step in the development was the development of models capable of predicting the future Pavement Condition Index (PCI) of a pavement feature, based on environmental and situational variables. These models are still considered tentative. The purpose of this thesis was to evaluate the current model proposed for predicting the PCI in flexible airfield pavements. The current model was found to be based on a statistically questionable change in the data. The current model was reaccomplished using a more accepted practice. The reaccomplished model was evaluated against a new data base and found to reasonably predict the PCI. The new and existing data was then combined, the model again was reaccomplished, and improvements noted. Two models were developed that show the possibility of interaction among the variables and the presence of nonlinear relationships. Finally, a model was developed, based on only the new data, which predicts the PCI very accurately for pavement on the base from which the data was gathered. This research should supplement CERL efforts to validate their models.

LSSR 11-83

AN EVALUATION OF THE PAVEMENT CONDITION INDEX PREDICTION MODEL FOR FLEXIBLE AIRFIELD PAVEMENTS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirement for the

Degree of Master of Science in Engineering Management

By

James D. Lyon, BSCE
Captain, USAF

September 1983

This thesis, written by

Captain James D. Lyon

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING MANAGEMENT

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William Schaur

COMMITTEE CHAIRMAN

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CHAPTER 1

INTRODUCTION

The single most important responsibility of Air Force Civil Engineering is the base airfield pavement. The success and safety of the flying mission require that this pavement be maintained in a condition of the highest possible quality. Because of the huge quantity of old pavement and the high cost of maintenance and repair, airfield pavements present a difficult management problem. About 70 percent of the Air Forces' 247 million square yards of airfield pavement is over 25 years old and is reaching the end of its design service life (1:1).

The quality of old pavement is reflected by the increased amount of money that the Air Force has spent, and is projected to spend, on the maintenance and repair of airfield pavements. In 1977, the Air Force spent 36.3 million dollars on the maintenance and repair of airfield pavements. In 1982, 88 million dollars were obligated, and the projection for 1983 is 108 million dollars to accomplish 269 projects. The Air Force is projected to spend about 625 million dollars from 1984 to 1988. Even with this great increase in spending, the backlog of validated but unfunded projects continues to be high. The backlog of projects in 1980 was 99.8 million dollars, in 1981 the backlog figure

rose to 117.6 million dollars, and then dropped to a 95.4 million dollar backlog in 1982. (15) The Air Force anticipated this great increase in required spending on pavement systems and contracted with the U.S. Army Construction Engineering Research Laboratory (CERL) for the development of an airfield pavement maintenance management system to improve the utilization of available funds (9:1).

The first thing that CERL did was to look at the condition surveys that the Air Force was using to evaluate pavements. They found that the evaluation procedures then in use (i.e., before 1975) lacked objectivity. There were few guidelines for the engineer on how to rate a pavement, therefore a large part of the rating depended on the engineer's experience and judgement. Those guidelines that were available failed to consider the severity of a particular type of distress. The result was a pavement evaluation of little aid in determining proper programming requirements for pavement maintenance and repair projects. (9:6-16)

CERL developed a new system, based on "pavement distress types, severities, and densities measured during an inspection of the pavement" (9:12). The developed system resulted in determination of a Pavement Condition Index (PCI), which is a numerical indicator ranging from zero to 100, with 100 representing new pavement. The system provides an objective pavement evaluation tool, which has provided consistent results among different pavement

engineers.(9:121) The Air Force has implemented the PCI method of pavement evaluation in the latest edition of Air Force Regulation 93-5. (17) The PCI method has proven so successful that the U.S. Army and the cities of Tampa FL, Ann Arbor MI, and Tacoma WA, among others, have all adopted the PCI method of determining pavement condition. Several consulting firms are also using the PCI method in determining the condition of municipal airfields. (8)

The second step in developing the pavement maintenance management system is to provide a method that the pavement engineer can use to predict future pavement condition, given various situational factors. Once this is done, alternative maintenance and repair actions, as well as changes in situational factors (such as mission changes), can be evaluated to determine their effect on the PCI. (11:1) Improved pavement management then becomes possible, because various maintenance and repair alternatives can be evaluated for their effectiveness and economy.

CERL has developed two basic models to forecast the PCI. The models are considered preliminary, since they are still being evaluated and improved upon (12:1). The first model predicts the PCI of rigid pavement, with or without a flexible overlay, while the other predicts the PCI of flexible pavement. Rigid pavement is a jointed surface that is generally bonded with Portland cement. Flexible pavement is generally an unjointed surface, bonded with

asphalt cement or tar. (4) Both models are based on a limited amount of field data and appear to reasonably predict PCI. Additional data is needed before the models can be fully validated (11:118-119). The prediction of pavement condition indices is the key to a successful pavement maintenance management system. The system provides a way to look into the future, to see how the pavement condition reacts under various environmental and situational factors so that the most cost effective mission and maintenance and repair alternatives can be selected.

Problem Statement

The current Pavement Condition Index prediction models are considered tentative, as they are currently being evaluated and revised. These models cannot be made a permanent part of the pavement maintenance management system until their validity is confirmed.

Research Objectives

The objective of this thesis is to validate the PCI prediction model developed by CERL for flexible pavements. Specifically:

1. Does the current model for flexible pavement reasonably predict pavement condition indices when applied to a new data base?

2. When new data are added to the existing field data, what is the effect on the PCI prediction model?

3. By using new and existing data, can the PCI prediction model for flexible pavement be improved upon?

4. Can a model be built for a particular base, using only the data from that base, that improves the prediction of the PCI as compared to the general model?

Research Approach

To accomplish the research objectives, this study will be approached as follows:

1. A thorough review of the literature on the pavement condition index system will be accomplished. Additionally, interviews will be conducted with the key people at CERL who helped develop the original prediction models.

2. A trip will be made to K.I. Sawyer AFB MI to gather flexible pavement data not used to develop the current prediction model. Actual PCI values will be determined in accordance with Air Force Regulation 93-5. Additionally, the records of various base organizations will be reviewed to collect data on all situational factors currently being used in the flexible pavement PCI prediction model.

3. The current prediction model for flexible pavement will be used to calculate PCI values. The new data will then be added to the existing data base and a

statistical analysis accomplished to see if the current model is changed.

4. The actual and predicted (i.e., model estimated) PCI values will be compared to determine the validity of both the current and refined models. Improvements to the prediction model will be made where deemed appropriate.

5. The new data collected will be statistically analyzed to see if a simple model can be produced that predicts PCI better, for the single base from which the data was collected, than the refined general model.

CHAPTER 2

LITERATURE REVIEW

The ability of the Air Force to predict pavement condition indices, based on various environmental and situational factors, is the result of a nine year effort to develop a pavements maintenance management system. Development was initiated in response to large increases in pavement maintenance and repair requirements that greatly exceeded available funds (9:1). The Air Force needed more effective methods of determining and predicting the condition of pavement to optimize the use of the limited funds available. This pavements maintenance management system is just one part of a general airfield pavement evaluation program that has been implemented through Air Force Regulation (AFR) 93-5 (17).

The objective of the airfield evaluation program is to gather data on all airfield pavements with, or with the potential for, Air Force missions. The data can then be used by civil engineering and operations personnel to better manage the airfield system. AFR 93-5 states (17:p.1-1):

> The results of pavement evaluation studies can be used to provide inputs for:
>
> 1) Determining the sizes, types, gear configurations, and gross weights of aircraft which can safely operate from a given airfield without damage to the pavements or the aircraft.

2) Developing operations usage patterns for a particular airfield pavement system (i.e., parking plans, apron utilization patterns, taxiway routing, etc.).

3) Projecting or identifying major maintenance and/or repair requirements for an airfield pavement system to support present or proposed aircraft missions, and in the event that pavement rehabilitation is required, furnishing the engineering data to aid in project design.

4) Assisting in base mission and contingency planning functions through the development of airfield layout and physical property data.

5) Developing and validating design criteria.

6) Supporting programming documents as justification for major pavement projects.

7) Supporting flying safety programs by providing pavement surface descriptions that indicate pavement surface traction and pavement roughness characteristics.

The pavement evaluation program consists of four parts: pavement evaluations, runway skid resistance surveys, runway roughness surveys, and condition reports (17:p.1-1). The first three require special training and equipment and thus are accomplished by mobile teams from the Air Force Engineering and Services Center (AFESC) at Tyndall AFB FL (17:p.1-1) The pavement evaluation consists of gathering data on the current physical properties of the pavement and determining the load carrying capacity (17:p.1-1). The runway skid resistance survey determines the wet and dry traction characteristics of a pavement surface and the roughness survey determines the pavement roughness (17:p.1-1). The last part of the pavement evaluation program is the condition survey. This is the only part of the program that can be performed by the base personnel (17:p.1-2). It is the condition survey that has received the greatest

amount of attention and is the keystone of the pavement maintenance management system being developed.

In 1974, the Air Force contracted with the U.S. Army Construction Engineering Research Laboratory (CERL) for development of a pavements program that would improve the use of pavement maintenance and repair dollars. Because of the increasing need for pavement maintenance and repair,

> . . . the Air Force has identified the need for an adequate method of describing and/or determining the relative condition of airfield pavements; and for developing procedures for evaluating the consequence of using various maintenance strategies to extend the service life of existing pavements. In addition, improved methods are needed for assignment of maintenance priorities to assure optimum use of available maintenance funds [9:1].

To meet the Air Force's goal of optimizing usage of pavement maintenance and repair funds, CERL began developing a pavement maintenance management system that includes (9:1-2):

1) Improved and field-validated condition survey procedures for jointed concrete, and asphalt or tar-surfaced airfield pavements.
2) Objective methods for determining pavement condition indices based on data obtained from pavement condition surveys.
3) A revised version of Air Force Regulation (AFR) 93-5, Chapter 3, entitled 'Airfield Pavement Condition Survey Report.'
4) Methods for evaluating the consequences of using various maintenance strategies; the methods will provide procedures for selecting the best specific maintenance strategies based on pavement condition.
5) Methods for assigning maintenance priorities which will assure efficient and economic use of available maintenance funds.
6) A computer package consisting of a data bank and computation system based on all the developments resulting from work described in 1 through 5. The computer package will provide an up-to-date pavement maintenance management system and will be easily adapted to any existing computers used by the Air Force.

7) Field demonstration of the final version of the pavement maintenance management system at one Air Force base will be required.

The pavement maintenance management system has met the first three objectives; improved condition survey procedures have been developed, objective indices determined, and AFR 93-5 has been revised (12:1). The fourth and fifth objectives (evaluating consequences of various maintenance and repair alternatives and assigning priorities based on the most efficient use of funds), are still under development, but should be ready for optional use by base pavements engineers by the fall of 1983 (2). An important part of evaluating maintenance and repair alternatives and performing an economic analysis, is the ability to forecast the future PCI to determine how various alternatives, and other situational factors, react over time (12:1). Even though the existing Pavement Condition Index prediction models are going to be available in the field, they are still being revised and improved upon (12:39). The purposes of this research are to evaluate the latest linear prediction model used for flexible pavement, plus add to the data base, and see if improvements can be made.

This literature review details the development of the PCI prediction models by reviewing the inadequate condition survey used prior to 1977, the development of the PCI condition survey by CERL, and the evolution of the prediction models themselves.

Early Condition Surveys

The pavement condition survey used by the Air Force, before the development of the Pavement Condition Index (PCI), was a subjective visual examination of the pavement (9:6). The results of these condition surveys varied greatly, depending on the experience and knowledge of the surveyor. The condition ratings established "were found to have poor correlation with pavement condition ratings made by a group of experienced pavement engineers [9:25]."

One of the main uses for the pavement condition rating was to support program documents for maintenance and repair projects (16:p.3-1). Even though the condition survey results were not consistent among different evaluators, it was still the main tool used by Air Force managers to determine whether or not a pavement was structurally sound. It is likely that many badly needed pavement projects were not funded because distant decision makers could not objectively identify the pavements in most need of work.

To better understand the problems that led to the development of the PCI, a review of the early condition survey methods is needed. First the methods used to determine the condition of rigid or jointed surfaced pavement will be reviewed, followed by a review of the early condition survey for flexible or asphalt/tar surfaced pavements.

Rigid Pavements

In order to perform a condition survey for rigid pavements, the airfield must be broken down into features. A feature is an area of pavement that is unique when compared to the rest of the airfield pavement. Examples of different features are: pavement of different thickness or design, pavement of different use, or pavement with a different construction history. (16:p.3-1) Features of airfield pavement are further defined in AFR 93-5 (17:p.2-1) and are outlined in Table 2-1.

Each pavement feature identified is further broken down into grids, with each section of the grid representing one slab of rigid pavement. The grid is "numbered consecutively from left to right and the individual slabs numbered from the starting point to the end [16:p.3-1]." This way, each slab is exactly located. The feature then can be surveyed by lane and slab number using the symbols in Figure 2-1 to record pavement defects. An example of a field recording of rigid pavement distresses is contained in Figure 2-2.

The surveyor takes the drawing of the feature grid and evaluates each slab for defects. "Any one of a number of defects may be recorded for one slab [16:p.3-2]." The symbol for a shattered slab is used when there are many structural defects (16:p.3-2).

The condition of rigid pavement is usually based on the "percentage of slabs, no major defects" or "percentage

TABLE 2-1

Features of An Airfield Pavement System [17:p.2-1]

Pavement Type:	A feature contains only one of the following types of pavement: (as defined in AFM 88-24, Chapters 2 and 3) flexible, jointed concrete, rigid overlay on rigid, nonrigid overlay on rigid, rigid overlay on flexible, composite, and reinforced rigid pavements.
Pavement Use:	Uses are basically runways, taxiways or aprons.
Pavement Thickness:	A discrete area having a constant nominal pavement thickness.
Construction History:	Pavement with a consistent construction history. This means the same: time of construction, contractor who constructed the pavement, construction materials, and construction techniques.
Traffic Areas:	Based on the lateral distribution of aircraft traffic and effective gross aircraft load. These areas are designated as Types A, B, C, and D as defined in AFM 88-6, Chapter 1.

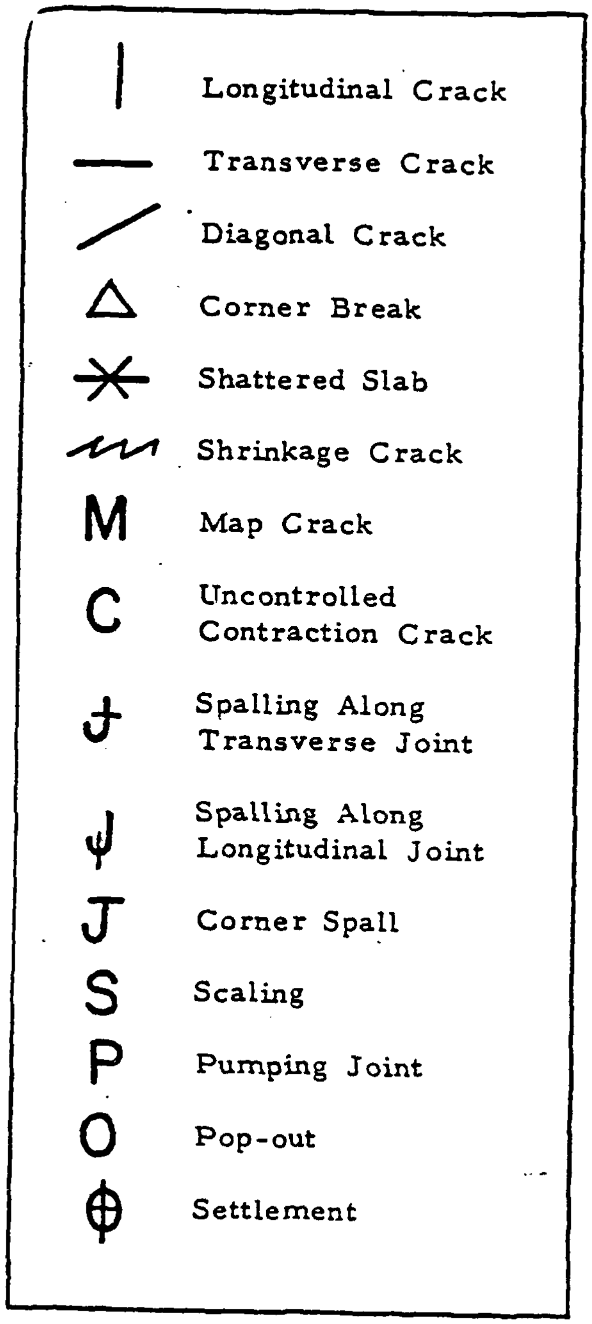


FIGURE 2-1

Distress Type Recording Symbols [16:p.3-2]

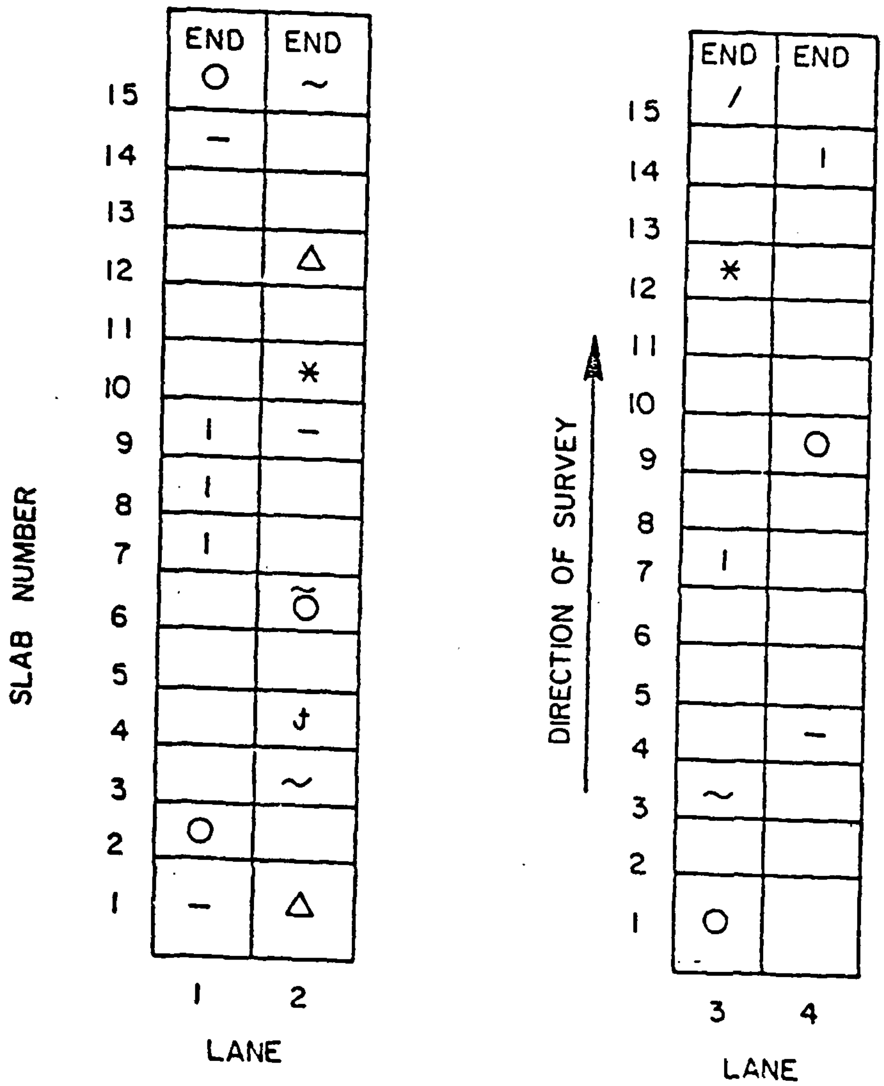


FIGURE 2-2

Example Condition Survey Format Showing Distresses in Rigid Pavement Feature [9:10]

of slabs, no defects" (16:p.3-2). These percentages are determined by dividing the total number of slabs with no major defects and no defects by the total number of slabs and multiplying by 100 (16:p.3-2). Once the percentages are known, the pavement condition can be determined using Table 2-2.

TABLE 2-2

General Guide for Establishing Rigid
Pavement Condition [16:p.3-3]

k = 25 to 200	k > 200	Condition Rating
% SLABS NO DEFECTS		
90 - 100	80 - 100	Excellent
80 - 98	70 - 90	Very Good
70 - 90	60 - 80	Good
60 - 80	50 - 70	Fair
<60 - 70	<50 - 60	Poor
% SLABS NO MAJOR DEFECTS		
98 - 100	90 - 100	Excellent
90 - 98	80 - 90	Very Good
80 - 90	70 - 80	Good
70 - 80	60 - 70	Fair
<70	<60	Poor

Engineering judgement must be used in determining what is to be deemed a "major defect." Most major defects are obvious, however:

> . . . when a number of minor defects are encountered and are noted to be producing debris or otherwise creating an aircraft operational hazard, they must be considered in the final assignment of a pavement condition [16:pp.3-2 to 3-3].

In other words, some minor defects may have to be considered major defects when trying to determine the pavement condition.

"The distribution of defects must also be taken into account [16:p.3 3]." For example, if most of the defective slabs are on the centerline of a taxiway or runway, the overall condition may be inflated by the high number of good slabs near the edges of the pavement. Engineering judgement must again be used to determine an appropriate pavement condition. (16:p.3-3) Unfortunately, CERL found that only the "percentage slabs, no major defects was used to determine the condition of the concrete pavement features in 95 percent of the [20] cases" reviewed (9:12).

After a review of the Air Force's early condition survey procedure, CERL concluded that it had two shortcomings (9:12):

> 1. Distresses are identified by type without considering severity. For example, a hairline crack has the same impact on a feature's condition rating as a crack that is severely spalled and is causing high foreign object damage (FOD) potential to jet aircraft.
>
> 2. Determination of the condition of a pavement feature based on percentage of slabs containing no defects or no major defects is inadequate. According to these guidelines [Table 2-2], a slab containing a transverse or longitudinal crack has the same influence on the feature's condition rating as a severely shattered slab that impairs aircraft operations. Percentage slabs containing a certain defect [of] specific severity would be a better parameter for condition rating.

To further test the accuracy of the condition survey, CERL had a group of experienced engineers evaluate several sections of pavement. They found that the engineers' average

condition rating correlated only on very good or excellent pavement. Otherwise, the average scores tended to underrate the pavement. (9:12) "For example, concrete pavements rated as poor by the Air Force procedure were rated as poor, fair, good, or very good by the engineers [9:12]."

Flexible Pavement

The early condition survey technique for flexible pavements was not nearly as well defined as the procedure for rigid pavement.

> The [early] condition survey accomplished on flexible airfield pavements [consisted] essentially of a visual inspection of the pavements for evidence of distress. Unlike the crack count method for rigid pavement rating, there [was] no present technique for assigning condition rating for flexible pavement condition. [16:p.3-3]

The technique relied almost entirely on the subjective opinion of the person performing the survey.

Some obvious defects in flexible pavement are jet blast and fuel spills; however, other types of distress require a careful survey to reveal their cause. Load induced distresses are "characterized by longitudinal cracking, springing under load, and rutting [16:p.3-3]." These defects could be caused by a failure in the subgrade, subbase, or the base course material. The closer the failure is to the surface, the more pronounced the distress (16:p.3-3).

Each distress was evaluated according to its effect on the load carrying and operational capabilities of the pavement. The following condition rating guide was provided

in the previous edition of AFR 93-5 (16:3-4):

> 1. GOOD. Pavements in better than average condition with no conspicuous evidence of deformation or incipient failures and with few (if any) longitudinal, transverse, or shrinkage cracks. All existing defects are being properly maintained.
>
> 2. FAIR. Pavements with a higher percentage of transverse, longitudinal, or pattern cracking and minor defects, such as weathered or oxidized surface, random cracking, and minor deformation or rutting.
>
> 3. POOR. Severe surface deformation, such as rutting, shear failure, densification, heave or raveling, extensive cracking, or evidence of surface water intrusion into moisture-sensitive subsurface layers. A reduction in allowable gross loading should be accomplished for pavements rated as poor.

These three condition categories did not define pavement problems clearly and were of little value in determining programming requirements (9:16).

After evaluating the early methods used by the Air Force to determine pavement condition, CERL found them inadequate. The main problem was a poor correlation between the condition surveys performed by the Air Force procedures and those obtained from a group of experienced pavement engineers. The recommended solution to this problem was to develop a new rating system "combining the effects of pavement distress types, densities, and severities [9:25]." The new rating system must then be validated by comparing the ratings with those "obtained by experienced pavement engineers [9:25]." This new system was developed and is called the Pavement Condition Index (PCI) Condition Survey.

PCI Development

The Air Force recognized problems in the early condition survey and contracted with the U.S. Army Construction Engineering Research Laboratory (CERL) for the development of a pavement maintenance management system (9:1). The success of this system depended on the development of a pavement condition survey rating procedure that met the following objectives (9:2):

> 1. To indicate the present condition of the pavement in terms of structural integrity and operational surface condition.
>
> 2. To provide the base civil engineer with an objective and rational basis for determining maintenance and repair needs and priorities, and with a warning system for early identification and/or projection of major repair requirements.
>
> 3. To provide the major commands with a common index for use in comparing the condition and performance of pavements at all operational bases within their jurisdictions and in determining justification for major repair projects, and to provide a basis for in-depth pavement evaluations by the [AFESC].
>
> 4. To provide Headquarters, U.S. Air Force (HQ USAF) with a rational basis for assigning priorities for in-depth pavement evaluations by [AFESC] specialty teams.
>
> 5. To provide feedback on pavement performance for validation or improvement of current pavement design procedures and maintenance practices.

During fiscal years 1975-76, CERL developed an airfield pavement rating procedure that meets the above objectives; it is called the Pavement Condition Index (PCI) (9:2). It is a numerical index ranging from zero to 100, with zero being completely failed pavement and 100 indicating perfect

pavement. The PCI method was "field tested, revised, and validated at nine airfields located in different climates and subjected to various traffic [9:2]." Figure 2-3 shows the locations of the nine airfields.

The PCI is computed "based on the type, severity, and density of pavement distress as determined from pavement inspection [10:1]." To make the PCI values consistent and meaningful, a standardized reference needed to be developed for distress identification and measurement (10:2). The standardized reference that CERL developed was based on a survey of 123 pavement sections located at the nine airfields shown in Figure 2-3 (9:26).

Forty of the pavement sections surveyed were jointed concrete (rigid) pavement. Twenty percent of the slabs showed at least one of the following types of distress (9:26):

1. Longitudinal/transverse/diagonal cracking
2. Scaling/map cracking/crazing
3. Patching, less than 5 square feet

These, plus another 12 types of distress identified in jointed concrete pavements, are listed in Table 2-3. The severity of all distress types varied across the pavements surveyed. (9:28)

In the 83 asphalt or tar-surfaced pavement sections surveyed, block cracking was the most common distress, being found in approximately 20 percent of the area (9:28).

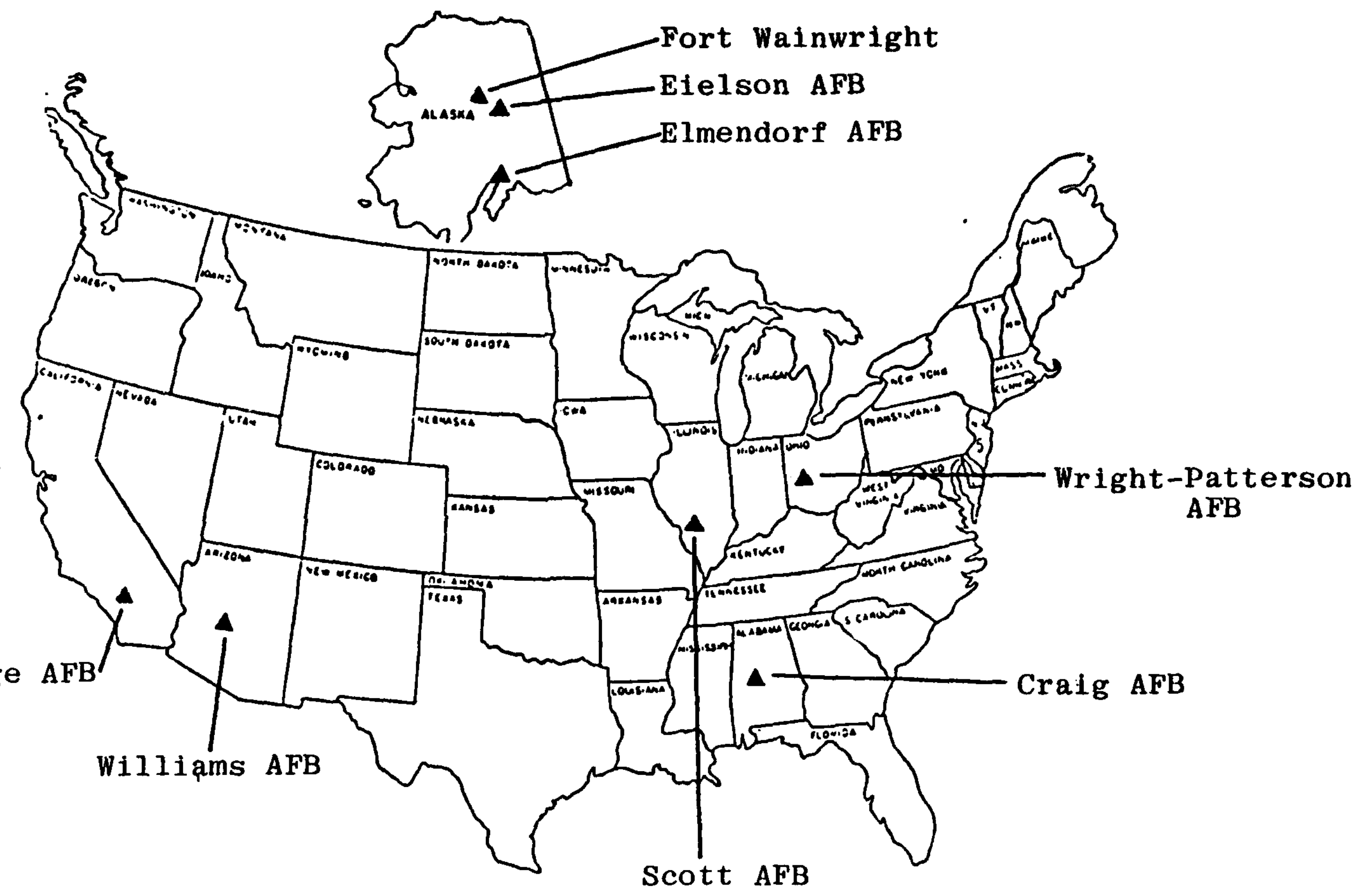


FIGURE 2-3

Airfields Surveyed for Testing and Validation of the PCI [9:3]

TABLE 2-3

Types of Distress in Airfield Pavement (9:21-22)

RIGID PAVEMENT	FLEXIBLE PAVEMENT
1) Blow-up	Alligator Cracking
2) Corner Break	Bleeding
3) Long./Trans./Diag. Cracking	Block Cracking
4) "D" Cracking	Corrugation
5) Joint Seal Damage	Depression
6) Patching (< 5 sq ft)	Jet Blast
7) Patching/Utility Cut	Joint Reflection Cracking
8) Popouts	Long. & Ref. Cracking
9) Pumping	Oil Spillage
10) Scaling/Map Cracking/Crazing	Patching
11) Settlement/Faulting	Polished Aggregate
12) Shattered Slab	Raveling/Weathering
13) Shrinkage Cracking	Rutting
14) Spalling--Joints	Shoving from PCC Slabs
15) Spalling--Corner	Slippage Cracking
16) N/A	Swell

Another 15 distress types were identified for asphalt pavement and are also listed in Table 2-3.

The identification of the various types of pavement distress and their severity levels provided a base upon which to build the PCI condition survey. Work began on a PCI survey for two types of pavement: jointed concrete and asphalt or tar-surfaced pavement. The process of testing, evaluating, and improving the PCI condition survey for both pavement types involved several months and many trials (9:39). The development of the PCI will be discussed by pavement type.

Rigid Pavement PCI Development

The efforts to develop the PCI for rigid pavements began at Tinker AFB OK (9:39). After reviewing literature on concrete pavement distresses and the results of 20 pavement condition surveys, "an initial set of distresses was selected and severity levels were defined [9:39]." A sample of 20 concrete slabs was then surveyed by a group of experienced pavement engineers to identify distresses.

All pavement started out with a PCI of 100 and was reduced by a deduct value representing distresses present. The initial deduct values were based on the limited experience gained thus far in the study.

> The deduct values were set according to the scale in Table [2-4] by subjectively estimating the maximum deduct for each distress and severity level at a maximum density, and then assuming a curvilinear relationship between the deduct value and density [9:39].

TABLE 2-4

Descriptive Pavement Rating Scale [9:38]

RATING SCALE	DESCRIPTION CATEGORIES
100 - 86	Excellent
85 - 71	Very Good
70 - 56	Good
55 - 41	Fair
40 - 26	Poor
25 - 11	Very Poor
10 - 0	Failure

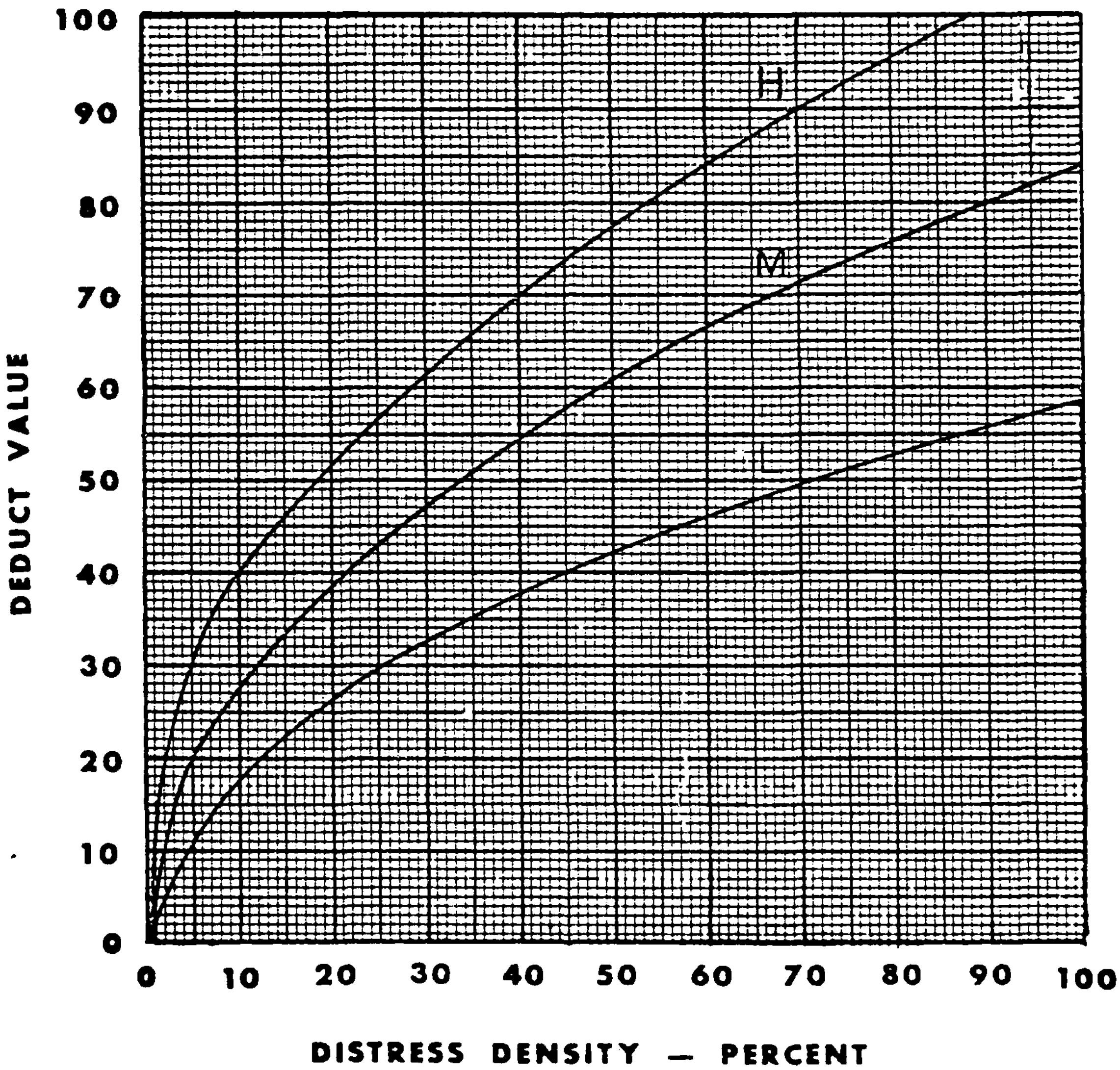


FIGURE 2-4

Jointed Concrete Pavement Deduct Value Curve for Shattered Slabs [17:p.3-20]

A density versus deduct value curve was developed for each type of distress. An example curve is shown in Figure 2-4.

Once the density versus deduct value curves for each distress type were established, the PCI of a pavement section could be calculated using the following expression (9:40):

$$PCI = 100 \sum_{i=1}^{P} \sum_{j=1}^{M_i} a(T_i, S_j, D_{ij}) \qquad (2\text{-}1)$$

where:

PCI = the Pavement Condition Index at age and traffic since construction or overlay

P = total number of distress types

i = a counter for distress types

M_i = the number of severity levels at the ith type of distress

j = a counter for severity levels

$a(T_i, S_j, D_{ij})$ = deduct for a given distress type T_i, at severity level S_j, and density D_{ij}.

After the PCI procedure was developed, CERL went to Wright-Patterson AFB OH for the first field test. Five jointed pavement sections were surveyed for distresses using the new procedure and a PCI was calculated using Equation (2-1). Four experienced pavement engineers then surveyed the same pavement, using the ratings in Table 2-4 (9-40). The average of the four pavement engineers' "condition ratings was computed for each section and called the Pavement

Condition Rating ($\overline{PCR}$) [9:40]."

The results obtained at Wright-Patterson AFB indicated two major deficiencies (9:40):

1. The definitions of several distress types and levels of severity did not describe actual conditions adequately.

2. The calculated PCIs for all five sections were much lower (i.e., 30 to 65 points) than the average subjective $\overline{PCR}$s of the engineers.

To solve these problems, the density versus deduct curves were revised and preparations made for a second field test (9:40-42).

The second field test was conducted at Williams AFB AZ and Craig AFB AL. Again, four experienced engineers subjectively rated 11 pavement sections and a mean $\overline{PCR}$ was determined. The PCI was calculated using the revised procedures from the field test at Wright-Patterson AFB. (9:42) The results indicated problems similar to those present in the first field test (9:42):

1. Some of the definitions did not clearly describe existing distresses.

2. The PCIs of sections containing several distress types were significantly less than the $\overline{PCR}$s.

An analysis of the results led to several changes. First, several "distress definitions were revised to reflect the experience gained during the second field test [9:42]." Second, it was determined that since the curves were based on a single defect, they overestimated the deduct value when there was more than one defect. The solution was to

adjust the curves to reflect the number of distresses as well as the magnitude of the deduct value. (9:42)

By subjectively rating several pavement sections with 2 to 8 distress types and/or levels of severity, a set of adjustment factor curves were constructed to correct the deduct values for multiple distress sections. Only distresses with a deduct value greater than 5 were counted, because smaller distresses have little effect on pavement condition. (9:44) These curves were used in all subsequent ratings with significantly improved estimation of the $\overline{PCR}$ (9:44). Equation (2-1) was changed to account for the adjustment factor as follows (9:40):

$$PCI = 100 - \sum_{i=1}^{P} \sum_{j=1}^{M_i} a(T_i, S_j, D_{ij}) F(t, d) \qquad (2\text{-}2)$$

where:

PCI = the Pavement Condition Index at age and traffic since construction or overlay

P = total number of distress types

i = a counter for distress types

M_i = the number of severity levels at the ith type of distress

j = a counter for severity levels

$a(T_i, S_j, D_{ij})$ = deduct for a given distress type T_i, at severity level S_j, and density D_{ij}

F(t, d) = an adjustment factor for multiple distresses that varies with total summed deduct value (t) and number of deducts (d)

Armed with an improved procedure, the CERL engineers went to Homestead AFB FL and Scott AFB IL to conduct the third field test of the PCI. After surveying 14 sections of pavement, CERL concluded (9:44):

> 1. Nearly all of the distresses observed at the two Air Force bases were adequately defined by the existing definitions. The definitions found to be deficient were revised.
>
> 2. The calculated PCI values for each section corresponded closely with the mean $\overline{\text{PCR}}$ ratings. However, a few of the deduct value curves required revision. The multiple distress [adjustment factor] curve improved the procedure significantly.

The engineers at CERL felt the PCI procedure was ready for a formal evaluation. The PCIs of the 30 pavement sections surveyed so far were computed using the latest revised procedure. (9:53) The results showed that (9:53):

> 1. The overall average $\overline{\text{PCR}}$ and PCI of all sections at each of the five airfields compared very closely (within 2 points).
>
> 2. The mean absolute difference between the $\overline{\text{PCR}}$ and PCI for all sections [was] relatively small (5.2 points). The differences [ranged] from 0 to 14 points.

The results of the evaluation strongly verified that the PCI procedure closely estimates the $\overline{\text{PCR}}$ from a group of experienced engineers. The PCI procedure was now considered ready for field validation (9:53).

The field validation was conducted on 10 jointed pavement sections located on four bases: George AFB CA, Elmendorf AFB AK, Eielson AFB AK, and Fort Wainwright AK. The results showed a mean absolute difference between the $\overline{\text{PCR}}$ and the calculated PCI to be 3.5 points. That compares

with a mean absolute difference of 5.2 points for the original 30 sections. Only a few corrections were made in the distress definitions and the deduct curves. (9:53)

The PCI procedure was now considered valid for determining the condition of rigid pavement. CERL determined the PCI procedure to have a 95 percent confidence of being within plus or minus 5 points of the $\overline{\text{PCR}}$ determined by a group of experienced engineers. (9:56)

Flexible Pavement PCI Development

The development of the PCI for asphalt and tar-surfaced pavements was conducted at the same time and used the same procedures as the PCI development for jointed concrete pavement. The first step again was to review the literature on asphalt pavement distresses and then to review condition survey reports done by the Navy at five of their installations (remember, the Air Force procedure was vague and not of much use). (9:61)

Based on the reviews and firsthand pavement observations from Tinker AFB OK, the CERL engineers determined that an adequate sample area for asphalt would be approximately 5,000 square feet. The distress density of a sample area was determined by the actual area of distress within the sample area divided by the total sample area (9:61). For example, if there was 150 square feet of raveled pavement in the 5,000 square foot sample, the distress density

would be:

$$\frac{150}{5,000} \times 100 = 3.0 \text{ Percent}$$

A crack was considered to have a width of one foot, so the above procedure would apply (9:61). For example, if there were 200 linear feet of cracks in 5,000 square feet, the distress density would be:

$$\frac{200}{5,000} \times 100 = 4.0 \text{ Percent}$$

Once the distress density was known, a PCI deduct value was applied. In the case of asphalt pavement, the density of a distress type was broken into discrete groups (9:62). Weighted "deduct values were assigned for each combination of severity level and density according to the subjective scale shown in" Table 2-4 (9:62). A sample deduct table is shown in Table 2-5.

TABLE 2-5

Initial Weighting of Deduct Values for Alligator Cracking [9:62]

Density	Severity		
	Low	Medium	High
Low (0.1 to 3.9 percent)	10	21	41
Medium (4.0 to 10.9 percent)	21	43	84
High (11.0 to 100 percent)	41	84	100

The first field test for asphalt or tar-surfaced pavement was conducted at Wright-Patterson AFB. Four asphalt-surfaced pavements were surveyed and a PCI computed using Equation (2-1). Four experienced pavement engineers then surveyed the same pavement, subjectively assigning a condition rating. The average of these four ratings was computed to determine a mean Pavement Condition Rating ($\overline{PCR}$). (9:62) The results indicated two major problems (9:62):

> 1. The definitions of several distress types and levels of severity did not describe actual conditions adequately.
>
> 2. The calculated PCI of two sections was reasonably close to the $\overline{PCR}$; however, two sections were considerably different.

Because the pavement in this first field test was all jointed pavement overlayed with asphalt, certain distress types (such as alligator cracking) could not be evaluated.

To correct the identified problems, the CERL engineers revised the distress definitions and the deduct values. It was also determined that deduct value curves, rather than discrete values, would provide better results. (9:62)

The second field test was done at Williams AFB AZ and Craig AFB AL (9:63). Using the revised procedures on 17 asphalt or tar-surfaced pavement sections, CERL found the following deficiencies (9:63):

> 1. Some of the definitions did not clearly describe existing distresses.

2. The PCIs for several distress types were significantly less than the $\overline{PCR}$s.

In an attempt to correct these problems, several distress definitions were revised and a correction factor devised that adjusted the deduct value when more than one type of distress was present in a pavement section (9:63).

The third field test was done on 17 asphalt or tar-surfaced pavement sections at Homestead AFB FL and Scott AFB IL (9:68). The PCI computed using the revised procedure was compared with the $\overline{PCR}$ of four experienced engineers. The results indicated the following (9:68):

1. Nearly all of the distresses observed at the two Air Force bases were adequately defined by the existing definitions. A few were found to be deficient and were revised (particularly alligator cracking, which occurred extensively at these airfields).

2. The calculated PCI values corresponded closely with the mean $\overline{PCR}$ ratings for each section. A few of the deduct value curves, however, required revision. The multiple distress [adjustment factor] curves improved the procedure significantly.

After the third field test, CERL felt that the PCI procedure was ready for a formal evaluation. The latest procedure was used to compute the PCI for all 38 pavement sections surveyed to this point (9:75). The PCI values obtained were then compared to the engineers' subjective $\overline{PCR}$ rating, with the following results (9:75):

1. The mean $\overline{PCR}$ and PCI [of] sections at each of the airfields [compared] very closely, with the overall mean showing only one point difference.

2. The mean absolute difference between the $\overline{PCR}$ and PCI for all sections [was] relatively small at 4.8 points. The differences [ranged] from 0 to 21 points.

The field validation for the asphalt or tar-surfaced pavement PCI was conducted on 35 sections located George AFB CA, Elmendorf AFB AK, and Eielson AFB AK. The results of the validation were even better than the results for the original 38 sections. The mean absolute difference between the $\overline{\text{PCR}}$ and the calculated PCI for the last 35 sections was 3.4 points, compared to 4.8 points for the original sections. (9:75) "A few deficiencies in distress definitions and deduct curves were identified and corrected [9:75]." An example of the final distress deduct value curves adopted is shown in Figure 2-5.

The results of the field validation indicated that there was a 95 percent confidence that the PCI of a feature was within plus or minus 4.75 points of the average condition rating, $\overline{\text{PCR}}$, that would have been determined by a group of experienced pavement engineers (9:81). The PCI procedure was now validated and ready for adoption by the Air Force.

PCI Procedure

The Air Force was satisfied with the end product of the Pavement Condition Index (PCI) development and has fully implemented this procedure of airfield condition survey in the latest edition of AFR 93-5. All operational bases are required to perform a PCI condition survey of their airfield pavements at least once every five years (17:p.1-1). The reaction of several Air Force pavement engineers is that the

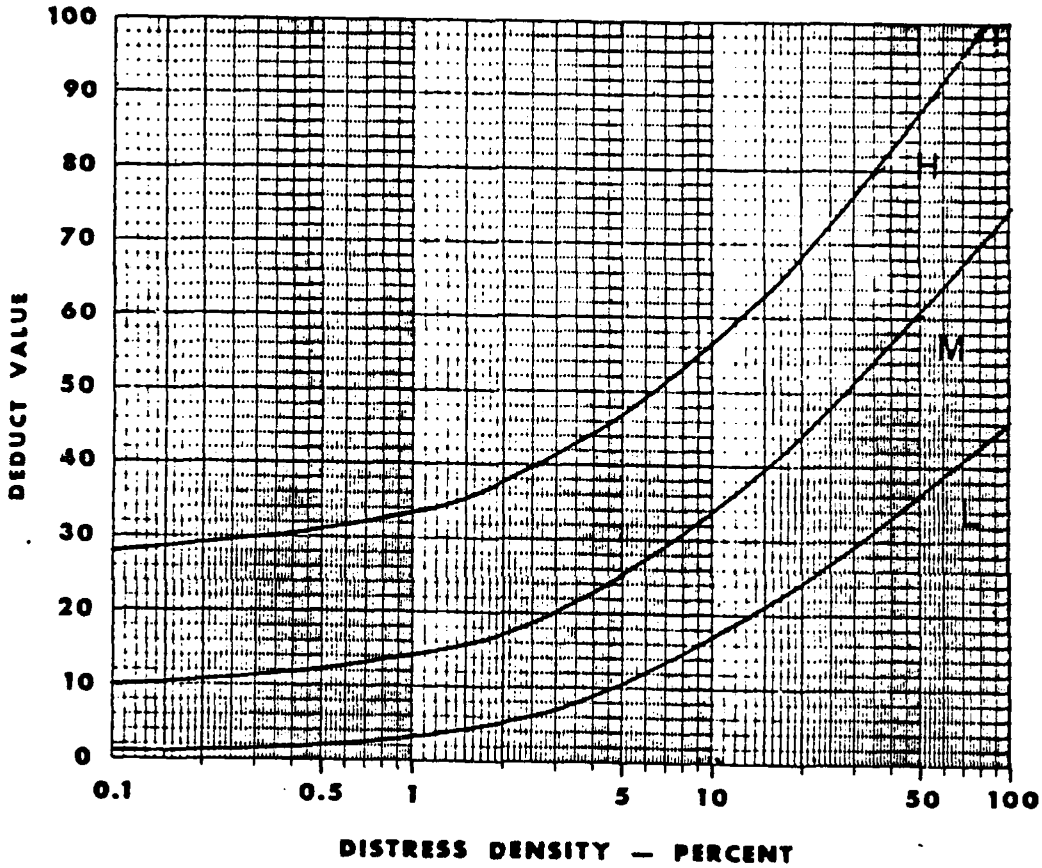


FIGURE 2-5

Asphalt or Tar-Surfaced Pavement Deduct Value Curves for Swell [17:p.3-39]

procedure has provided them with a very effective management tool for deciding how and where to use airfield pavement maintenance and repair funds. The engineers feel that the PCI condition survey is a total success. (2; 5) Although a detailed description of the PCI procedure is available in AFR 93-5, a brief review is required for continuity in this literature review.

The PCI is determined for each operational feature of the airfield. Features were previously defined in Table 2-1. Once the features are defined, they are broken into sample units for survey. A sample unit of jointed concrete pavement consists of approximately 20 slabs, while the sample unit for asphalt or tar-surfaced pavement is an area of approximately 5,000 square feet. Each sample unit is surveyed and all distress types, their severity, and their density recorded. (17:p.3-1) "For each distress type, density, and severity level within a sample unit, a deduct value is determined from the proper curve [17:p.3-1]." Examples of these curves were shown in Figures 2-4 and 2-5. All deduct values for each distress condition in a sample unit are added together to find the Total Deduct Value (TDV). The TDV is then adjusted for the number of distress conditions observed, with only individual deduct values of more five points being counted (17:p.3-1). The adjusted TDV is called the Corrected Deduct Value (CDV) and is determined from Figure 2-6 for jointed concrete and Figure 2-7 for

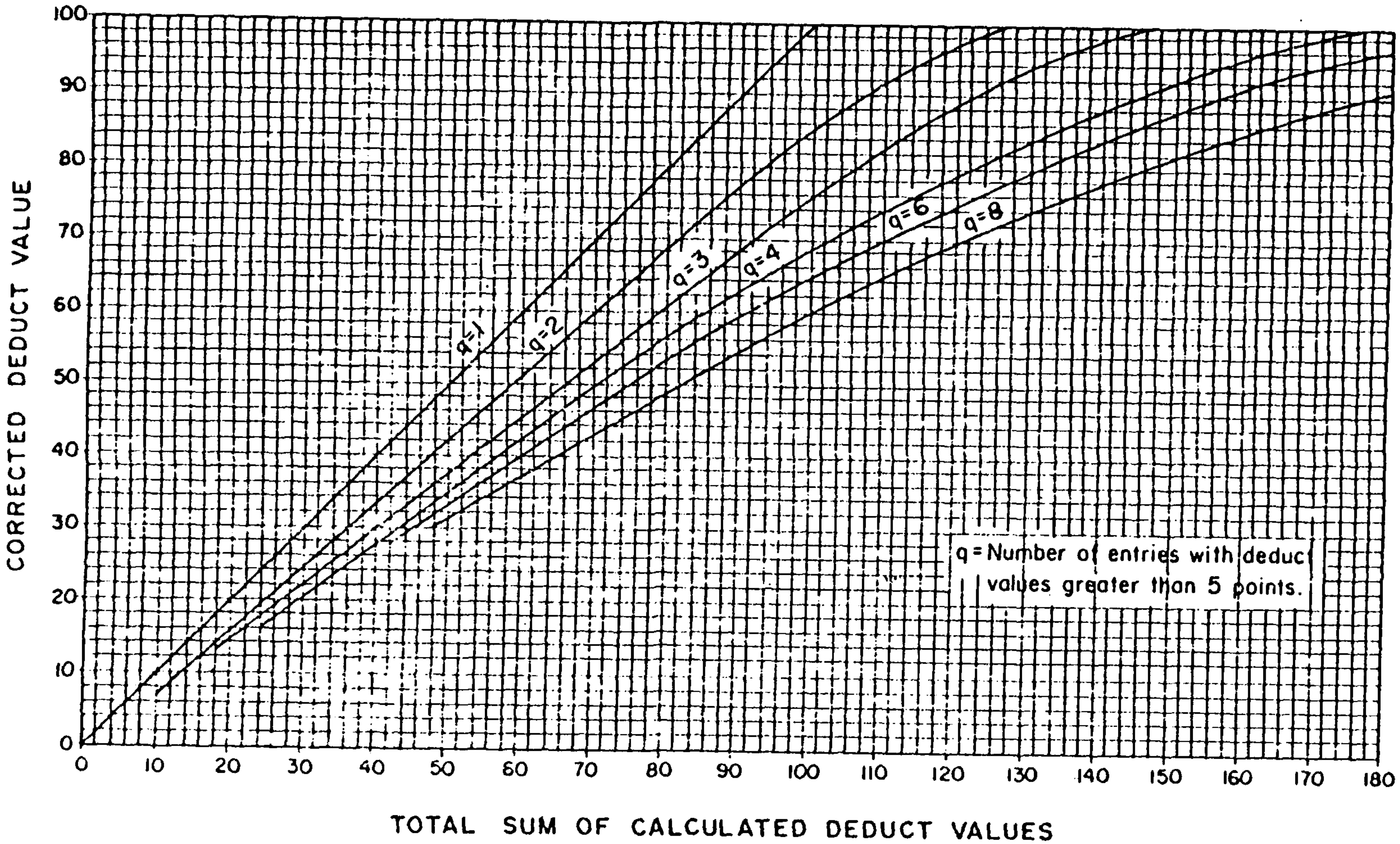


FIGURE 2-6

Corrected Deduct Values for Jointed Concrete Pavements [17:p.3-41]

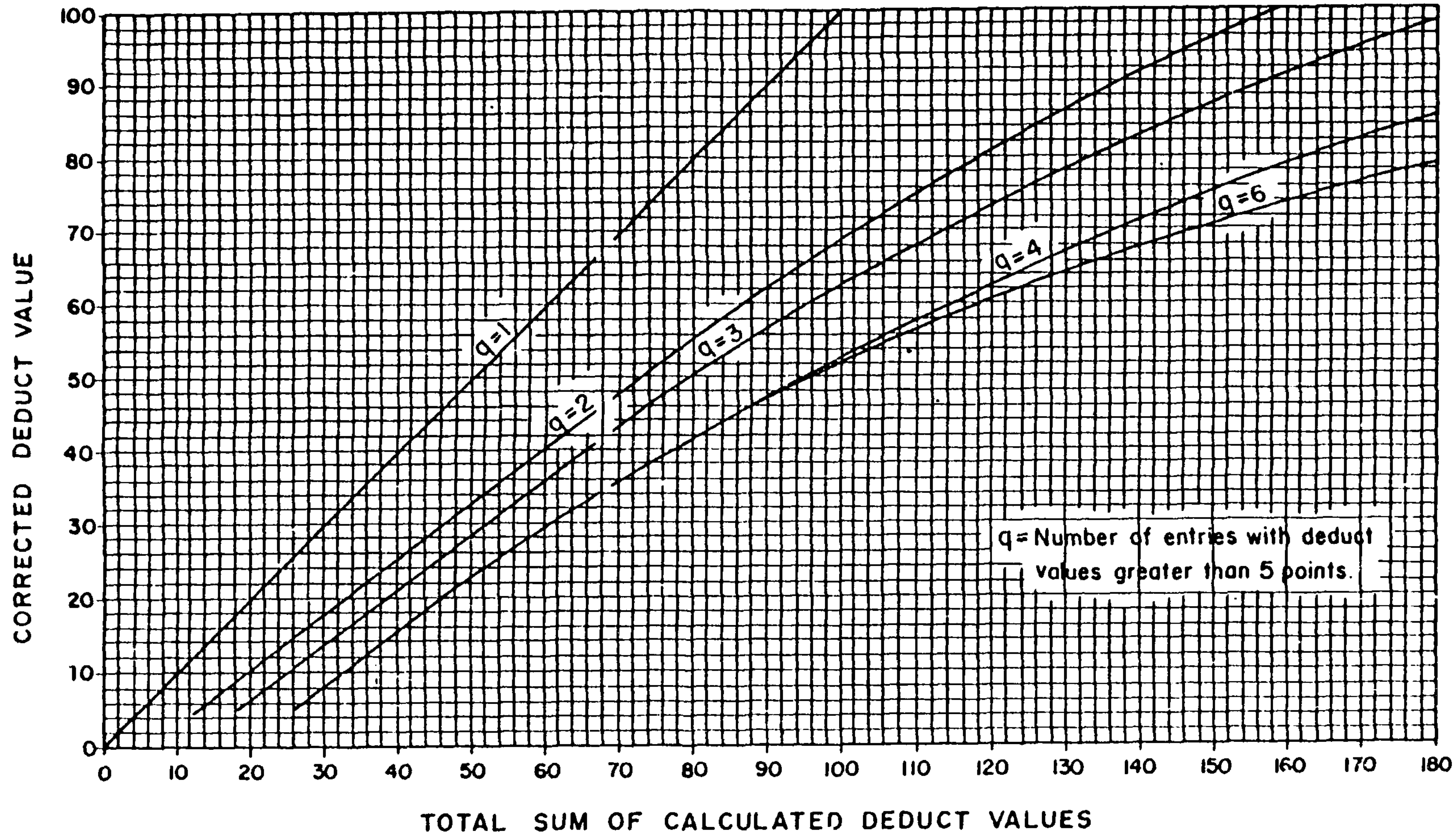


FIGURE 2-7

Corrected Deduct Values for Asphalt- or Tar-Surfaced Pavements [17:p.3-41]

for asphalt or tar-surfaced pavement. The PCI for each sample unit is determined as (17:p.3-1):

$$PCI = 100 - CDV \qquad (2\text{-}3)$$

where:

PCI = the Pavement Condition Index at age and traffic since construction or overlay

CDV = the Corrected Deduct Value

There is a possibility that the CDV will be less than the highest individual deduct value for a given sample unit. In that case, the highest deduct value should be used instead of the CDV. (17:p.3-1)

The PCI of the entire pavement feature being surveyed is the average of that feature's sample unit PCIs. The PCI is then compared to values in Table 2-4 to determine the pavement condition. (17:p.3-1)

A summary of the PCI condition survey process is contained in Figure 2-8.

Performing a pavement condition survey on an entire pavement feature can be a considerable effort. To help those units with limited resources or for units at bases that cannot allow runway access for a long period of time, a random sampling procedure was developed to provide an adequate estimate of the PCI (17:p.3-2). To help the base pavement engineer calculate a large number of PCIs, the Air Force has adopted a computer program, available on the Base

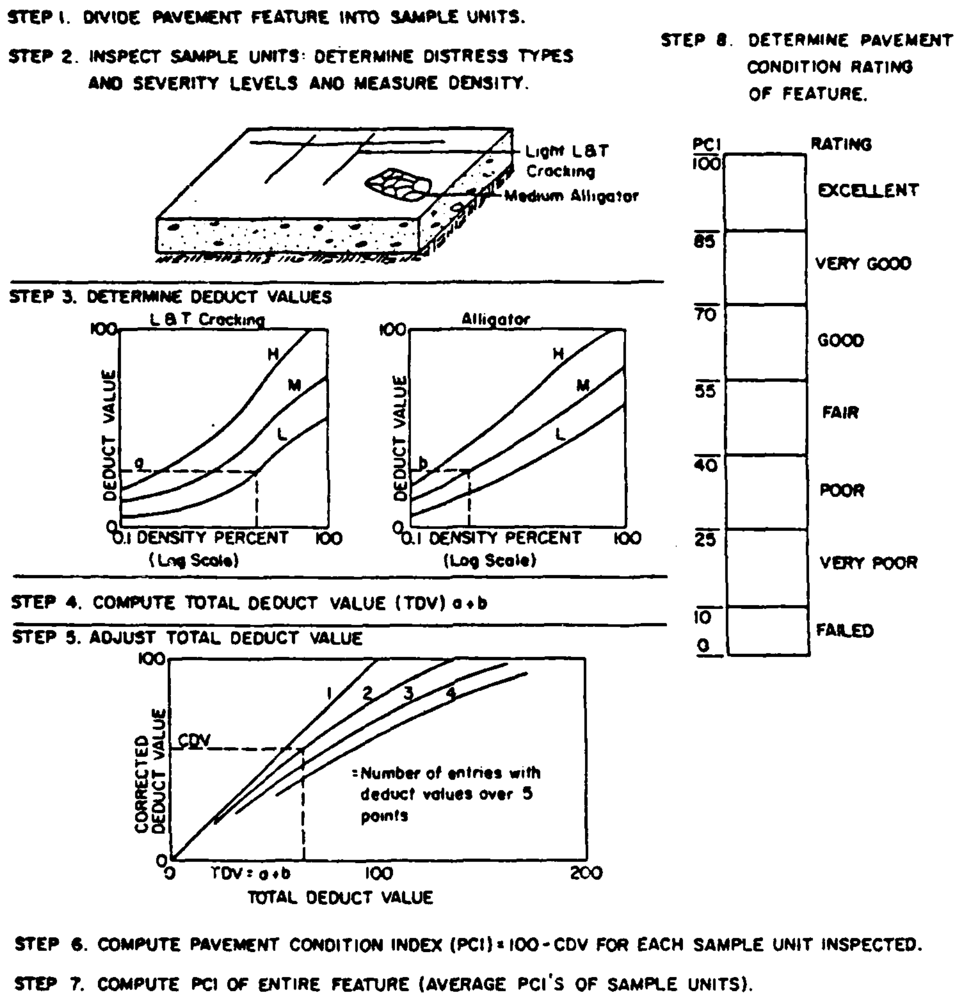


FIGURE 2-8

Steps for Determining PCI of a Pavement Feature [17:p.3-5]

Engineer Automated Management System (BEAMS), that computes the PCIs for any number of sample units and features (17:p.3-3). These two developments have greatly increased the usability of the PCI condition survey.

Prediction Model Development

The PCI procedure was implemented by the Air Force in Fiscal Year 1977. The next step in developing an overall pavement maintenance management system was to find methods for evaluating the consequences of maintenance alternatives and mission changes. (9:1-2) In order to determine maintenance and repair needs and the effects of future missions, it is first necessary to be able to predict the PCI (11:1). The prediction of the PCI "should also provide insight into the variables that cause deterioration of pavements [11:40]."

The U.S. Army Construction Engineering Research Laboratory (CERL) has been working on several models to predict PCI since 1977 (11:6). Both linear and nonlinear statistical evaluations of the data base have been made (4).

Early Rigid/Flexible Models

In order to develop PCI prediction models, CERL built a data base with information collected from the 19 Air Force bases shown in Figure 2-9 (11:8). The data was obtained from survey's done by CERL in fiscal years 1976 through 1978, from historical information, pavement

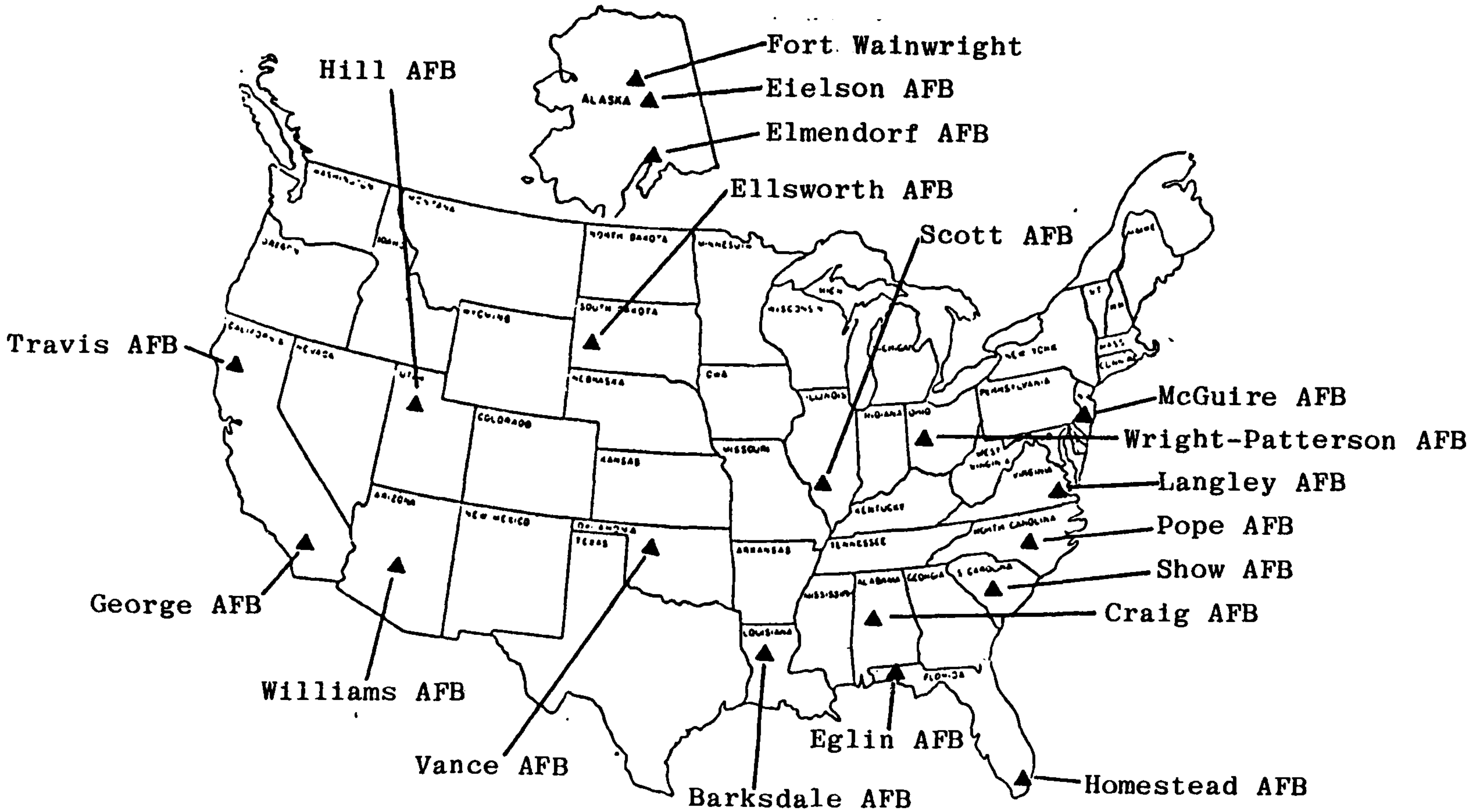


FIGURE 2-9

Airfields Surveyed for Developing the Early PCI Prediction Models [11:9]

evaluation reports, and from interviews of major command or base pavement engineers (11:8). "In addition to the raw data, several new variables were created that combined the effects of two or more variables [11:8]."

> The first step in model development was to identify all major variables (called independent variables) believed to significantly influence the PCI. This was accomplished by reviewing literature, interviewing major command and base pavement engineers, and reviewing previous experience of the project staff. The availability of information, cost, and time required to collect each independent variable for each airfield feature was assessed, and it was concluded that several variables could not be obtained within the available resources. Table [2-6] lists the independent variables considered important in the development of the concrete pavement prediction models and those from which data were actually collected. [11:40]

The initial prediction model for rigid pavements was derived from data on 67 concrete features having no overlay, 19 concrete features with an asphalt overlay, and five concrete features having a concrete overlay. A summary of the data on rigid pavement is contained in Table 2-7.

CERL used the Statistical Package for the Social Sciences (6) to perform all data analyses (11:41). The first step involved the use of several SPSS subprograms to obtain "frequency plots, cross tabulation tables, and graphs of each independent variable (i.e., AGE, FI, FAT) vs the dependent variable (PCI) [11:42]." One result was a correlation matrix used to determine which variables were related to each other and needed to be combined. The SPSS procedure

TABLE 2-6

List of Independent Variables Considered in the Development of the Concrete Pavement PCI Prediction Models [11:41]

I. Variables used to develop early rigid models (data gathered for each feature):

AGE	(Time Since Original Construction of Slabs) -- Years
SLAB	(Concrete Slab Thickness) -- Inches
BASE	(Granular Subbase Thickness) -- Inches
JSL	(Longest Joint Spacing) -- Feet
JSS	(Shortest Joint Spacing) -- Feet
MR	(Modulus of Rupture of Concrete) -- psi
K	(K-Value of Slab Foundation) -- Pounds/ Cubic Inch
ACWGT	(Gross Maximum Weight of Critical Aircraft Using Feature) -- Kips
FAT	(Ratio of Stress to Modulus of Rupture x 100)
PEI	(Pavement Evaluation Index)
FEAT	(Type of Feature: Runway, Taxiway, Apron)
AREA	(Traffic Area: A, B, C)
PS	(Usage of Feature: Primary or Secondary)
FI	(Freezing Index) -- Degree Days Below 32 Degrees F
PPT	(Average Annual Precipitation) -- Inches
TEMP	(Average Annual Temperature) -- Degrees F
SR	(Slab Replacement) -- Percent of Total Slabs
PATCH	(Large Patching) -- Percent of Total Slabs
ACOL	(Existence of AC Overlay)
PCOL	(Existence of Concrete Overlay)

II. Other variables considered which had important effects on PCI data, but were not obtained because of cost, time required, or lack of availability:

Number of Aircraft Passes Over Feature
Joint Design
Joint Load Transfer Efficiency
Several Additional Climatic Variables (Number of Freeze-Thaw Temperature Gradients Through Slab, Monthly Distribution of Precipitation, etc.)
Drainage Condition of Pavement Feature

TABLE 2-7

Summary of Data for Concrete Pavement Features With and Without an Overlay (11:8-21)

Factor	Concrete		Concrete/Concrete Overlay		Concrete/Asphalt Overlay	
	Mean	Range	Mean	Range	Mean	Range
PCI	70.6	36-97	75	60-90	70.5	48-87
Cracking (% Slabs)	16.6	0-71	24	0-56	---	---
Age Original Slab (Years)	19	2-34	33	22-37	28.7	17-37
Age of Overlay (Years	---	---	17	12-23	9.5	4-21
Original Slab Thickness (Inches)	12.3	6-22	10.8	6-19	9.8	6-21
Subbase Thickness (Inches)	---	---	0	0	6.3	0-30
Overlay Thickness (Inches)	---	---	8.6	8-10	2.7	1.5-8.0
Modulus of Rupture (psi)	739	520-922	730	700-800	711	600-850
K-Value (pci)	163	30-500	98	60-130	197	60-500
Freezing Index (Degree Days Below 32°F)	99	0-678	0	0	392	0-2070
Average Annual Rainfall (Inches)	30.7	3.5-56	34.8	7-47	---	---
Average Annual Temperature (°F)	58.3	46-75	63.0	60-69	52.8	31-69
Tensile Stress/Flexible Strength	0.37	0.15-0.80	0.36	0.23-0.52	0.70	0.28-1.61

"Regression" with the "Stepwise" method of selecting independent variables was used to determine the actual model (11:42).

Regression analysis is the description of the nature of a relationship between two or more variables (3:472). For the regression analysis of PCI data, it was assumed that there exists a linear relationship between the PCI (the dependent variable) and all independent variables.

Stepwise is a procedure available in the SPSS "Regression" subroutine that builds a model by entering independent variables into the equation in the order of their significance (6:120). Significance is determined using the F test (or equivalent t test) (6:120). Each time a new variable is added to the model, the variables previously added are checked to insure their continued significance (6). Any variable that is no longer significant is eliminated from the model (6:120). "The more independent variables there are entering the equation, the better the equation will fit or model the data for predicting PCI [11:42]."

In multiple linear regression, all independent variables can be shown to have some relationship, even if very small, to the dependent variable. To eliminate variables that did not contribute to the PCI prediction model for rigid pavements, a significance level of 0.05 was used (11:42). This means that only variables explaining five

percent or more of the variation in the PCI were permitted to enter the model.

After running the SPSS Stepwise Regression program several times over a period of months, the following tentative model for the prediction of PCIs on rigid pavement was selected (11:52):

$$PCI = 100 - AGE[0.01967\ FAT - 0.02408\ SR + 0.001051(JSL \times JSS) + 0.94191\ ACOL + 0.03475\ PATCH + 2.91238 - 0.001775\ FI - 0.04066\ TEMP] \qquad (2\text{-}4)$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

AGE = time since construction of slab or, if overlaid, time since overlay construction (years)

FAT = (ratio of interior slab stress/modulus of rupture) x 100

SR = slab replacement (percent total slabs)

JSL = longest joint spacing (feet)

JSS = shortest joint spacing (feet)

ACOL = 1 if asphalt overlay exists
0 if concrete overlay exists

PATCH = slabs containing large patches (5 square feet), percent of total slabs, or percent area of total area patched if overlaid with asphalt

FI = freezing index (degree days below 32 degrees F)

TEMP = average annual temperature (degrees F)

The coefficient of determination (R squared) for this model was 0.37, which means 37 percent of the variation in the PCI is explained by the variables in the model. The standard deviation was 10.5. (11:52)

Equation (2-4) was evaluated using several criteria. The model meets the boundary conditions. That is, when AGE is zero, the PCI equals 100. The coefficients of all independent variables are reasonable in that they all have a negative effect on the PCI as AGE increases. Other criteria were also satisfied and the results of the evaluation and a sensitivity analysis indicated that Equation (2-4) was useful in predicting the PCI for rigid pavement. Several deficiencies were identified, including an insufficient data base (91 features); therefore, the model can only be considered tentative. (11:56-58)

The development of a model to predict the PCI in flexible pavements paralleled the development of the rigid model. Again, "a literature review, interviews with major command and base pavement engineers, and the previous experience of the project staff" were used to identify the major factors influencing flexible pavement deterioration (11:71). The factors are listed in Table 2-8. The same 19 bases shown in Figure 2-9 were used for data gathering. There were 37 total features included in the model, 26 from flexible features with no overlay and 11 flexible features with

TABLE 2-8

List of Independent Variables of Asphalt Pavement [11:72]

AC (no overlay):

AGEOR	(Ages of Pavement) -- Years
TAC THICK	(Total AC Thickness) -- Inches
B THICK	(Base Thickness) -- Inches
SB THICK	(Subbase Thickness) -- Inches
B CBR	(Base CBR) -- Percent
SB CBR	(Subbase CBR) -- Percent
SG CBR	(Subgrade CBR) -- Percent
ACWGT	(Aircraft Weight) -- Kips
AREA	(Traffic Area, Type A=1, Type B=2, Type C=3)
P/S	(Primary=1, Secondary=2)
FEAT	(Feature, Apron=1, Taxiway=2, Runway=3)
ZONE	(Environmental Zone: Wet, Freeze=1; Seasonally Wet, Freeze=2; Dry, Freeze=3; Wet, Freeze-Thaw=5; Dry, Freeze-Thaw=6; Wet, No Freeze=7; Seasonally Wet, No Freeze=8; Dry, No Freeze=9)
FI	(Freezing Index, Degree Days (Below 32 degrees F))
PPT	(Precipitation) -- Inches
AAT	(Annual Average Temperature) -- Degrees F
ADTR	(Annual Daily Temperature Range) -- Degrees F
AATR	(Annual Average Temperature Range) -- Degrees F
α_{AC}	(Load Repetition Factor for AC Thickness/Interface Base)
α_{SG}	(Load Repetition Factor for Subgrade)
T Equiv Thick	(Total Equivalent Thickness of Pavement) -- Inches
# Equiv Thick	(Load Repetition Factor for Total Equivalent Thickness of Pavement)
TAC	(Total Alligator Cracking) -- Percent of Sample Units
PATCH	(Patching) -- Percent of Sample Unit

TABLE 2-8 (Continued)

AC Pavement with AC Overlay:

Variables for AC pavement with no overlay plus the following:

AGEOL	(Age after Overlay) -- Years
AGECOL	(Age between Original Construction and Overlay) -- Years
ACOL Thick	(AC Thickness for Overlay) -- Inches
TAC Thick	(Total AC Thickness) -- Inches
AGE	(Age after Original Construction or Overlay) -- Years

an asphalt overlay (11:91). A summary of the flexible pavement data is contained in Table 2-9.

The SPSS Stepwise Regression program was run on the data to determine which independent variables had a significant affect on the dependent variable, PCI (11:71). All variables were interacted with AGE to insure that when the pavement is new (AGE=0), the PCI will be 100 (11:96). After trying to develop a prediction model for both flexible pavements with no overlay and flexible pavements with an overlay, CERL selected the following combined model as reasonably predicting the PCI for both types of flexible pavement (11:96).

$$PCI = 100 - AGE[1.487/\alpha_{SG} + 0.143\ AGECOL + 6.56/TAC - 12.3\ \alpha_{AC}] \tag{2-5}$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

AGE = age since original construction or, if overlaid, time since overlay construction (years)

α_{SG} = load repetition factor determined at the subgrade level; α_{SG} is a function of total pavement thickness above the subgrade, subgrade CBR, and the tire contact area and tire pressure of an equivalent single wheel

AGECOL = age between the time the pavement was constructed and the time it received the last overlay; equals zero if no overlay

TAC = total asphalt thickness in inches, including overlay, if any

TABLE 2-9

Summary of Data for Asphalt Pavement Features With and Without an Overlay (11:23-39)

	Asphalt		Asphalt/Asphalt Overlay	
	Mean	Range	Mean	Range
PCI	61	12-100	56.8	17-83
Alligator Cracking (Percent)	6.4	0-51	5.6	0.09-26.5
Patching (Percent)	0.135	0-0.6	0.85	0-4.7
Age of Original Construction (Years)	18	0.5-35	28	19-35
Age of Overlay (Years)	---	---	9.4	4-23
Original Thickness of ACC (Inches)	3.9	2-7.5	4.2	2.5-6.5
Thickness of ACC Overlay (Inches)	---	---	2.4	0.5-16.5
Base Thickness (Inches)	9.5	2-27	8.0	4-16.5
Subbase Thickness (Inches)	9.4	0-28	8.2	0-42
Base CBR (Percent)	71	24-100	56	24-100
Subbase CBR (Percent)	24.7	0-100	26	0-100
Subgrade CBR (Percent)	21.8	4-80	20	5-50
Freezing Index (Degree Days Below 32°F)	175	0-2070	1095	0-5320
Precipitation (Inches)	31.7	7-56	29.6	3.5-47
Average Annual Temperature (°F)	59.7	36-69	50.8	26-61
Average Annual Temperature Range (°F)	40.0	15-51	22	19-29
Average Daily Temperature Range (°F)	21.7	15-31	46	35-61
Load Repetition Factor at ACC/Base Interface	0.70	0.34-1.30	.83	0.43-1.43
Load Rep. Factor at Subgrade Level	1.48	0.72-2.83	1.25	0.59-3.0
Load Rep. Factor at Subgrade Level Based on Equivalent Thickness	1.89	0.818-3.06	1.50	0.73-3.42

α_{AC} = load repetition factor determined at the asphalt/base interface

The coefficient of determination (R squared) for Equation (2-5) was 0.62 and the standard deviation was 14.4 (11:100). The model was acceptable in that it met the required boundary conditions for the PCI (between zero and 100) and was reasonable based on engineering experience (11:96). The primary deficiency in the model was lack of a large data base (37 features) (11:102).

CERL concluded that the PCI of both rigid and flexible pavement can be predicted based on "specific pavement variables such as structural design, aircraft load, material properties, subgrade properties, and climate parameters [11:119]." The models, at this point, were to be considered only as tentative, until additional data could be collected and used to develop more comprehensive models (11:119).

Current Model Development

The efforts to develop the early PCI prediction models proved "that it was feasible to predict [pavement] condition using empirical regression models developed from field data and other methods such as probabilistic theory [13:1-2]." The results, however, were based on a very limited amount of data so, in fiscal year 1980, a comprehensive data collection effort began so that more adequate models could be developed (13:2).

The data collected included 327 rigid and flexible airfield pavement features from the 12 Air Force bases shown in Figure 2-10 (13:4,6).

> The data were obtained from (1) Air Force pavement evaluation reports, (2) construction records in the base engineering office and other historical records, and (3) the recollection of long time employees on past traffic missions and current traffic flows on airfield features. Some data, such as traffic, were very difficult to obtain, but even subjective estimates were considered to be better than no data at all. [13:6]

Additional variables, called mechanistic variables, were calculated using computer programs with some of the field data (13:6-7).

After the data was collected, it was checked carefully for any obvious errors. The errors were then corrected, or if corrections were not possible, the erroneous data was eliminated (13:7).

Initially, data was collected on all the variables thought to cause deterioration in pavement (13:7). Table 2-10 contains a list of the variables collected on rigid pavement features and Table 2-11 contains the list of variables collected on flexible features. During the modeling process, many variables were found to have no significant effect on the PCI and were eliminated from further consideration (13:7). The primary data used to develop the current models for PCI prediction is summarized in Table 2-12 for rigid pavement data and Table 2-13 for flexible pavement data.

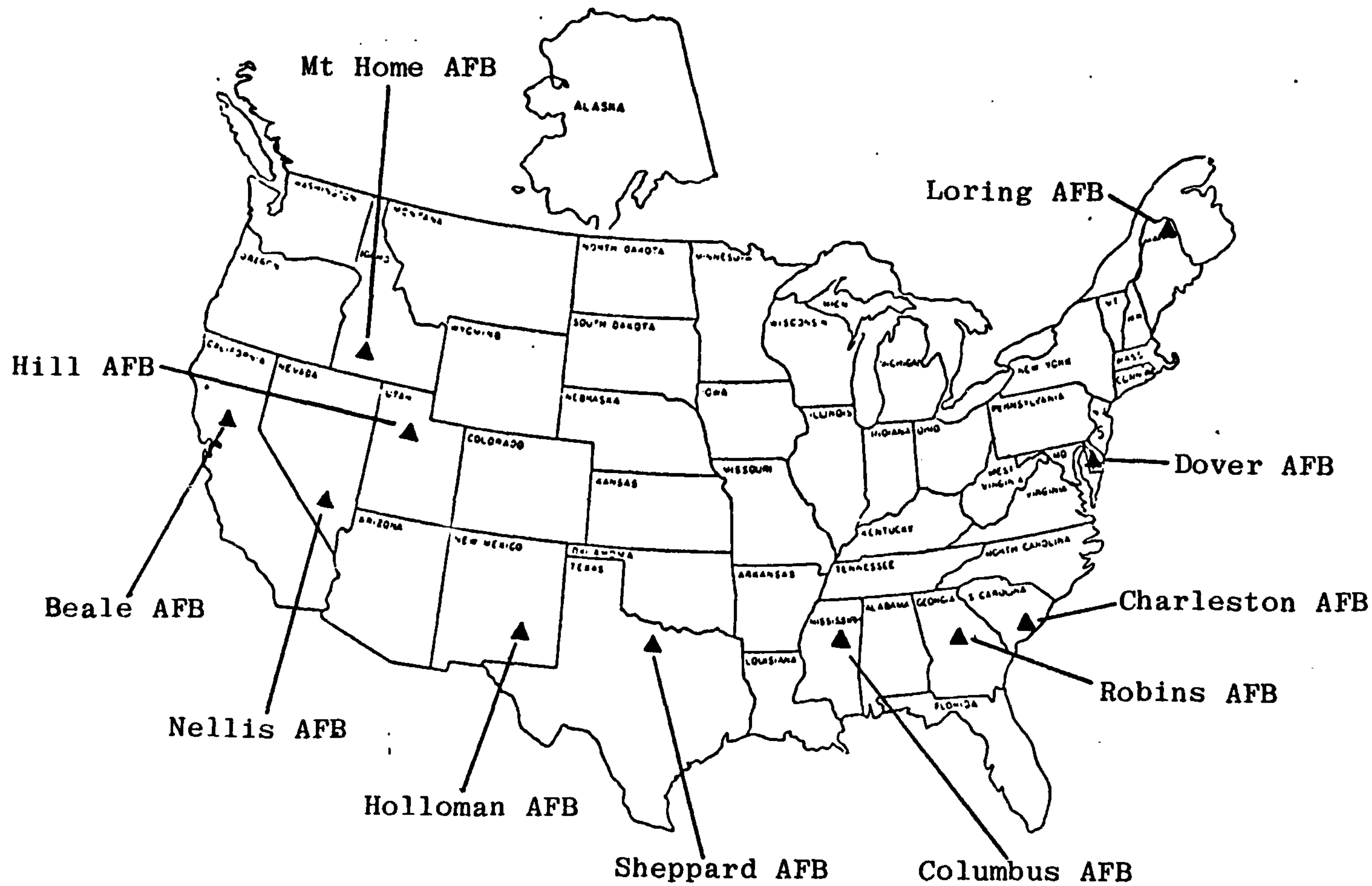


FIGURE 2-10

Airfields Surveyed for Developing Current CERL PCI Prediction Models [13:5]

TABLE 2-10

List of Raw Data Variables Considered in the Development of the Concrete Pavement PCI Prediction Model [13:8]

FYTYPE	(Feature Type: Runway, Taxiway, Apron)
FWIDTH	(Feature Width) -- Feet
FLENGTH	(Feature Length) -- Feet
FAREA	(Feature Area) -- Square Feet
SURDATE	(Original Surface Placement Date) -- Year
SURTHICK	(Original Surface Thickness) -- Inches
SURMR	(Original Surface Modulus of Rupture) -- psi
BDATE	(Base Layer Placement Date) -- Year
BMATL	(Base Material) -- Coded
BTHICK	(Base Thickness) -- Inches
BK	(K-Value on Top of Base) -- Pounds per Cubic Inch
BMR	(Base Modulus of Rupture, Cement Stabilized Only) -- psi
JSL	(Slab Length) -- Feet
JSW	(Slab Width) -- Feet
LJDPL	(Joint Design, Longitudinal Paving Lane) -- Coded
TJD	(Joint Design, Transverse) -- Coded
JFILLER	(Joint Filler, Original) -- Coded
SGMOD	(Subgrade Modification, if any) -- Coded
SGMATL	(Subgrade Material) -- Coded
SGK	(K-Value on Top of Subgrade) -- pci
HZOTABLE	(Depth of Water Table) -- Feet
PMSTART	(Present Mission Starting Date) -- Year
PMSTOP	(Present Mission Ending Date) -- Year
PMCAT1	(Amount of Usage Category #1 Accounts for This Pavement Feature) -- Percentage
PMANOPS	(Number of Repetitions Per Year This Pavement Feature) -- Percentage
CRFILL	(Overall Maintenance Policy) -- Coded
JTCRFLI	(Joint/Crack Fill Interval) -- Years
SRAREA	(Slabs Replaced) -- Percentage of Total Area
SRAGE	(Average Age of Replaced Slabs) -- Years
FI	(Average Freezing Index) -- Degree Days Below 32 Degrees F
FTC1	(Average Annual Number of Freeze-Thaw (F-T) Cycles at 1-Inch Depth)
FTC2	(Average Annual Number of F-T Cycles at 2-Inch Depth)
FTC3	(Average Annual Number of F-T Cycles at 3-Inch Depth
AAPREC	(Average Annual Precipitation) -- Inches

TABLE 2-10 (Continued)

AATEMP	(Average Annual Temperature) -- Degrees F
ADTR	(Average Daily Temperature Range) -- Degrees F
AATR	(Average Annual Temperature Range) -- Degrees F
THORMI	(Thornthwaite Moisture Index)
AASR	(Average Daily Solar Radiation) -- Langleys
JULSR	(July Daily Solar Radiation) -- Langleys
PEVAP	(Potential Evaporation) -- Inches
OPEVAP	(Open Water Evaporation Potential) -- Inches
AAWS	(Average Annual Wind Speed) - mph

TABLE 2-11

List of Raw Data Variables Considered in the Development of the Asphalt Pavement PCI Prediction Model [13:9-10]

FTYPE	(Feature Type: Runway, Taxiway, Apron)
FWIDTH	(Feature Width) -- Feet
FLENGTH	(Feature Length) -- Feet
FAREA	(Feature Area) -- Square Feet
SURDATE	(Original Surface Placement Date) -- Year
SURPASPH	(Surface Layer Percent Asphalt)
SURAVOID	(Surface Layer Air Voids) -- Percent
SURFVOID	(Surface Layer Filler Voids) -- Percent
SURMS	(Surface Layer Marshall Stability) -- Pounds
SURFLOW	(Surface Layer Flow Measurement) -- 0.01 Inches
SURPEN	(Surface Layer Penetration) -- mm X 10^{-1}
BDATE	(Base Layer Placement Date) -- Year
BMATL	(Base Material) -- Coded
BTHICK	(Base Thickness) -- Inches
BCBR	(Base Layer California Bearing Ratio [CBR])
BMS	(Base Layer Marshall Stability) -- Pounds
BDENSE	(Base Layer Density) -- Percent of Optimum
BMOIST	(Base Layer Moisture Content) -- Percent
JSL	(Slab Length) -- Feet
JSW	(Slab Width) -- Feet
LJDPL	(Joint Design, Longitudinal Paving Lane) -- Coded
TJD	(Joint Design, Transverse) -- Coded
JFILLER	(Joint Filler, Original) -- Coded
SGMOD	(Subgrade Modification, if any) -- Coded
SGMATL	(Subgrade Material) -- Coded
SGCBR	(Subgrade CBR)
PI	(Plasticity Index for Subgrade)
LL	(Liquid Limit for Subgrade)
SGOPTMC	(Subgrade Optimum Moisture Content)
SGINSMC	(Insitu Subgrade Moisture Content)
SGDENSE	(Subgrade Density) -- Percent of Optimum
HZOTABLE	(Depth of Water Table) -- Feet
PMSTART	(Present Mission Starting Date) -- Year
PMSTOP	(Present Mission Ending Date) -- Year
PMCAT1	(Amount of Usage Category #1 Accounts for on This Pavement Feature) -- Percentage
PMANOPS	(Number of Repetitions per Year This Pavement Feature) -- Percentage
CRFILL	(Overall Maintenance Policy) -- Coded

TABLE 2-11 (Continued)

FI	(Freezing Index) -- Degree Days Below 32 Degrees F
FTC1	(Average Annual Number of Freeze-Thaw (F-T) Cycles at 1-Inch Depth)
FTC2	(Average Annual Number of F-T Cycles at 2-Inch Depth)
FTC3	(Average Annual Number of F-T Cycles at 3-Inch Depth)
AAPREC	(Average Annual Precipitation) -- Inches
AATEMP	(Average Annual Temperature) -- Degrees F
ADTR	(Average Daily Temperature Range) -- Degrees F
AATR	(Average Annual Temperature Range) -- Degrees F
THORMI	(Thornthwaite Moisture Index)
AASR	(Average Daily Solar Radiation) -- Langleys
JULSR	(July Daily Solar Radiation) -- Langleys
PEVAP	(Potential Evaporation) -- Inches
OPEVAP	(Open Water Evaporation Potential) -- Inches
AAWS	(Average Annual Wind Speed) -- mph

TABLE 2-12

Means and Ranges of Key Rigid Pavement Variables (13:11)

	Mean Value	Range
Layer Information Variables		
Age -- years	18.0	2-37
PCC thickness -- inches	15.3	2-24
Modulus of rupture -- psi	701	480-992
Base material -- coded	---	---
Base thickness -- inches	12.7	2-55
Subgrade material -- coded	---	---
Modulus of subgrade reaction (k) -- pci	240	15-500
Environmental Variables		
Average annual temperature -- °F	60.0	38.8-65.8
Average annual precipitation -- inches	29.7	3.8-52.1
Freezing index -- degree days	127.4	0-1980
Freeze-thaw cycles -- 2-inch depth	25.8	0-111
Water table -- feet	100	4-500
Discrete Variables		
Feature type -- coded	---	---
Crack filling policy -- coded	---	---
Primary or secondary -- coded	---	---
Mechanistic Variables		
Fatigue	68,430	352-612,654
Damage	425.86	0-26,420

TABLE 2-13

Means and Ranges for Key Flexible Pavement Variables (13:12)

	Mean Value	Range
Layer Information Variables		
Age -- years	10.58	0-27
Original AC thickness -- inches	3.80	2.0-7.0
Total AC Thickness -- inches	5.85	2.0-14.0
Base material -- coded	---	---
Base CBR -- percent	85.13	20-100
Total select thickness -- inches	30.62	0.0-67.0
Subgrade material -- coded	---	---
Subgrade CBR -- percent	17.80	6-88
Environmental Variables		
Average annual temperature -- °F	54.2	38.0-65.8
Average annual temperature range -- °F	45.2	31.6-54.2
Average daily temperature range -- °F	23.4	19.1-28.5
Average annual precipitation -- inches	26.2	3.8-52.1
Average annual solar radiation -- langleys	407	325-520
Freezing index -- degree days	491	0-1980
Freeze-thaw cycles -- 2-inch depth	26.5	0-99
Water table -- feet	100	4-500
Discrete Variables		
Feature type -- coded	---	---
Crack filling policy -- coded	---	---
Primary or secondary -- coded	---	---

TABLE 2-13 (Continued)

	Mean Value	Range
Mechanistic Variables		
Weighted average surface deflection (present period) -- (inches/equivalent single wheel load [ESWL])	0.001	0-.005
Weighted average surface deflection (first previous period) -- inches/ESWL)	0.001	0-.002
Weighted average vertical stress on base (present period) -- psi	86.2	0-175
Weighted average vertical stress on base (first previous period)	59.7	0-203
Cumulative vertical stress on base (present period) -- (psi, number of passes)	1.039×10^{7}	$0\text{-}1.414 \times 10^{8}$
Cumulative vertical stress on base -- (first previous period)	6.841×10^{6}	$0\text{-}1.163 \times 10^{8}$
Cumulative vertical strain on subgrade (present period) -- (0.001 inches, number of passes)	6.067×10^{5}	$0\text{-}8.881 \times 10^{6}$
Cumulative vertical strain on subgrade (first previous period) -- 0.001 inches, number of passes)	4.771×10^{5}	$0\text{-}1.274 \times 10^{7}$

After many runs using SPSS Stepwise Regression, several reasonable models were developed for predicting the PCI in rigid pavements (13:27). The most recent linear model that CERL has developed for the prediction of PCI in rigid pavement is as follows (13:28-29):

$$PCI = 97.6 - 0.33180(AGE \times LDAM) - 0.0023015(AGE^2 \times \sqrt{FTC}) - 0.00046622(AGE^2 \times PREC) - 0.000042041(AGE^2 \times \sqrt{FAT}) \qquad (2\text{-}6)$$

where:

PCI = Pavement Condition at age and traffic since construction or overlay

AGE = time since original construction or, if overlayed, time since overlay construction

LDAM = $LOG_{10}(DAMAGE + 10.0)$

$$DAMAGE = \sum_{i=1}^{a} n_i/N$$

a = number of different aircraft using feature

n_i = total number of passes of aircraft over feature

N = number of repetitions of aircraft load to cause failure of concrete

FTC = number of freeze-thaw cycles at a 2 inch depth/year

PREC = average annual precipitation, inches

$$FAT = \sum_{i=1}^{a} (0.75Te_i/MR)n_i$$

Te_i = edge stress computed by H-51 program

MR = modulus of rupture of concrete

An evaluation of Equation (2-6) concluded that the model is reasonable in predicting the PCI of rigid pavement (13:31-35). The coefficient of determination is 0.64 and the standard deviation is 9.6 (13:28). The total sample size was 168 rigid features (5).

The boundary conditions for the PCI (zero to 100) were not met when AGE equals zero. The model shows the PCI at AGE equal zero to be 97.6. The PCI could be made to have a PCI of 100 when AGE equals zero, by forcing the model through the origin. Since 97.6 is close to 100, it was decided not to change the model because any change would also decrease the model's accuracy as AGE increased. (13:31)

The results of other evaluations were encouraging. The coefficients of the independent variables all seemed reasonable and the sensitivity analysis also looked promising (13:28-31).

The SPSS Stepwise Regression procedure was also run on the 70 flexible features of the data base (5). The following is the most current linear model for the prediction of the PCI in flexible pavement and will be the subject of further evaluation in this thesis (13:47-48):

$$PCI = 96.817 - 7.0733(ADAV)(AGE) - 0.00050865(\sqrt{VCR})(AGE) - 0.048290\left[\frac{(PRECI)(AGE)}{THICK}\right] \qquad (2\text{-}7)$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

ADAV = AD x AV

AD = weighted average surface deflection divided by equivalent single wheel load

AV = weighted average vertical stress on top of the base course

AGE = time since original construction or, if overlaid, time since overlay construction (years)

$$VCR = \sqrt{\sum_{i=1}^{a} (\sigma_v)(N)}$$

σ_v = vertical stress on top of base course before most recent overlay

N = number of passes before most recent overlay

a = number of types of aircraft

PRECI = average annual precipitation (inches)

THICK = thickness of asphalt layer most recently constructed (inches)

Equation (2-7) was found to have a coefficient of determination of 0.71 and a standard deviation of 9.51 (13:47).

The model (Equation (2-7)) was evaluated and did not meet the boundary condition of having a PCI of 100 when AGE equals zero. This is because the model was not forced through the origin. The model does, however, meet the basic condition that the PCI decreases as AGE increases. Since a PCI of 97.6 is reasonably close to 100, it was decided

not to force the model through the origin to preserve accuracy as AGE increases (13:50).

Equation (2-7) is also reasonable and plausible. As expected, the coefficients all are inversely related to the PCI. Also, most of the variable categories normally thought to influence the deterioration of flexible pavement are present. These categories include traffic, climate, materials, construction, asphalt layer and subgrade stresses, foundation design, previous maintenance, and overlays. (13:50) Many of these variable categories do not appear directly in the model but are used to compute the mechanistic variables (AD, AV, σ_v) using the computer program BISAR (Bitumen Structures Analysis in Roads) developed by Shell Oil Company (14).

The model was also subjected to a sensitivity analysis to determine the degree of influence that changes in each of the variables has on the PCI (13:52). The results indicated that Equation (2-7) is a reasonable predictor of the PCI in flexible pavements (13:59). "A significant finding was that the rate of deterioration after [an] overlay is greatly influenced by the amount of structural damage before [an] overlay [13:59]."

Dronen Model

In 1982, Captain Michael Dronen performed an evaluation of a linear model for the prediction of the PCI in

rigid pavement. Captain Dronen gathered data from 12 rigid pavement features located at Wright-Patterson AFB OH and added that data to the existing CERL data base (1:79). The prediction model developed by CERL was found to be incapable of predicting the actual PCI of the Wright-Patterson AFB pavement features (1:107).

In an effort to improve the ability to predict the PCI of rigid pavements, Captain Dronen investigated the possibility of the existence of a nonlinear relationship between PCI and the independent variables. The investigation led to several new variables created from various combinations of variables in the data base. A summary of the new combined data base is shown in Table 2-14. A SPSS Stepwise Regression analysis resulted in the following model (1:121-122):

$$\begin{aligned} PCI = 98.2 &- 0.7467189(I_1LDAM9) \\ &+ 0.4456063 \times 10^{-2}(II_1LDAM9) \\ &- 0.6599812 \times 10^{-4}(I_2FATR) \\ &- 0.3101097 \times 10^{-4}(PREAG) \\ &- 0.6928678 \times 10^{-4}(DAMFT) \\ &- 0.1493424 \times 10^{-2}(III_2AGECOL) \\ &- 0.4455170 \times 10^{-2}(DAMAG) \end{aligned} \tag{2-8}$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

TABLE 2-14

A Summary of Data Used in Developing the Modified Improved PCI Prediction Model (1:123)

Variable	Mean	Range	Standard Deviation
AGE (Years)	17.63	1.0 - 37.0	7.08
AGECOL (Years)	3.08	0 - 30.0	7.03
Freeze-Thaw Cycles	23.34	0 - 105.0	40.52
Annual Precipitation (Inches)	30.51	3.8 - 52.1	16.77
FAT	81818.61	352.0 - 658325.0	122139.47
DAMAGE	8450.93	0 - 282780.0	38836.26
DAMCOL	13551.75	0 - 568460.0	73708.11
THICK (Inches)	0.74	0 - 8.0	1.82
I_1LDAM9	27.38	1.01 - 140.14	23.26
I_2FTCR	1064.91	0 - 5101.49	1867.98
I_2PRECI	10807.41	15.20 - 54512.50	9017.77
II_2AGECOL	11.39	0 - 197.97	35.17
LDAMCOL	1.34	1.0 - 5.76	1.06
I_2FATR	78747.19	22.19 - 709414.89	87631.48
II_1LDAM9	1287.48	1.02 - 19638.84	2707.28
III_2AGECOL	1359.70	0 - 39192.74	5798.44
DAMFT	25465.50	0 - 250276.26	47405.39
PREAG	61805.41	---	202030.69
DAMAG	590.71	0 - 9855.58	2023.02
Actual PCI	73.51	17.0 - 98.0	16.44

$I_1LDAM9 = AGE[LOG_{10}(DAMAGE + 10)]$

AGE = time since original construction or, if overlaid, time since overlay

DAMAGE = pavement damage factor

$II_1LDAM9 = (I_1LDAM9)$

$I_2FATR = AGE^2\sqrt{FAT}$

FAT = pavement fatigue factor

$PREAG = I_2PRECI \times II_2AGECOL$

$I_2PRECI = AGE^2$(annual precipitation)

$II_2AGECOL = \sqrt{AGE}(AGECOL)(LDAMCOL)/THICK$

AGECOL = pavement age before overlay

LDAMCOL = pavement damage before overlay

THICK = most recent overlay thickness

$DAMFT = I_1LDAM9 \times I_2FTCR$

$I_2FTCR = AGE\sqrt{\text{number of freeze-thaw cycles at 2 inch depth}}$

$III_2AGECOL = II_2AGECOL$

$DAMAGE = I_1LDAM9 \times II_2AGECOL$

The model resulted in a coefficient of determination (R squared) of 0.71 which is a singificant improvement over the R squared of 0.65 found in the original CERL model. The evaluation of the model showed it to be reasonable and "it can be concluded, the modified improved PCI prediction model [Equation (2-8)] provides the best possible estimate of the

actual condition of the 12 rigid airfield pavement features located at Wright-Patterson AFB [1:126]."

Conclusion

The Air Force has a large amount of old and rapidly deteriorating airfield pavement. As the gap between the cost of repairs and available funds widened, it was realized that a comprehensive pavement maintenance management system was needed to increase the effectiveness of maintenance and repair decisions. The U.S. Army Construction Engineering Research Laboratory (CERL) was contracted to develop such a system.

The first thing CERL did, was to investigate the system the Air Force was using to determine the condition of airfield pavements. The investigation revealed that the pavement condition survey in use prior to 1975 was very subjective and provided inconsistent results.

Work was begun in 1974 to develop a new, objective, method of determining pavement condition. After several years of work, the Pavement Condition Index (PCI) condition survey was developed and adopted by the Air Force.

The PCI is a numerical index ranging from zero to 100, with zero being totally failed pavement and 100 being new pavement. It is "based on the type, severity, and density of pavement distresses as determined from a pavement inspection [10:1]." Most Air Force pavement engineers feel

the PCI condition survey has resulted in a vast improvement in their ability to effectively evaluate pavement and determine maintenance and repair strategies.

As an additional step in the development of a comprehensive pavement management system, models were created based on airfield pavement data to predict future PCIs. The ability to predict the PCI is critical in order to evaluate various maintenance and repair or mission alternatives for airfield pavements.

Several models have been developed and improved upon. They are based on operational, construction, and environmental data from Air Force airfield pavements located all around the country. The latest models, presented in this literature review, have been shown to be reasonable predictors of the PCI; however, the models are still considered tentative until their validity can be proven.

CHAPTER 3

RESEARCH METHODOLOGY

Scope and Delimitation

As was established in the literature review, models for predicting pavement condition have been developed for two basic types of pavement. The first type of pavement is rigid and includes concrete (Portland Cement) without an overlay, concrete pavement with a concrete overlay, and concrete pavement with an asphalt or tar-based overlay. The second type of pavement, for which prediction models have been developed, is flexible pavement. Flexible pavement consists of asphalt or tar-based pavement with or without an asphalt or tar-based overlay

In his 1982 thesis, entitled "An Evaluation of the Pavement Condition Index Prediction Model for Rigid Airfield Pavements," Captain Michael Dronen studied the PCI prediction model for rigid pavement (1). To compliment that study, and to provide a more complete research effort, this thesis involves an evaluation of the prediction model for flexible airfield pavement.

The methodology was designed to satisfy the research questions presented in Chapter 1. In summary, data was gathered and the latest model for flexible pavement (Eq 2-7)

was tested for its validity in predicting the PCI for features not used in the development of the model. The newly gathered data was then combined with the old data base and attempts were made to improve the present model. An attempt was also made to develop a PCI prediction model for K.I. Saywer AFB using only data from that base, to see if it predicts the PCI better for that base than the general model.

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), the same package used by CERL to develop their models. Computer support involved the use of the Control Data Corporation "Cyber" computer for the statistical analyses and the CREATE system for the computation of the actual PCIs of the new data features. The CERL computer system was used for the calculation of the mechanistic variables.

Data Collection

Data for this study was obtained from two sources. The first source of data was from CERL. This data included traffic, construction, environmental, and condition information on 70 flexible pavement features located at the 12 Air Force bases shown in Figure 2-10.

The second source of data was K.I. Sawyer AFB MI. The data included traffic, construction, environmental, and pavement condition information on the 11 flexible airfield pavement features shown in Figure 3-1. The features

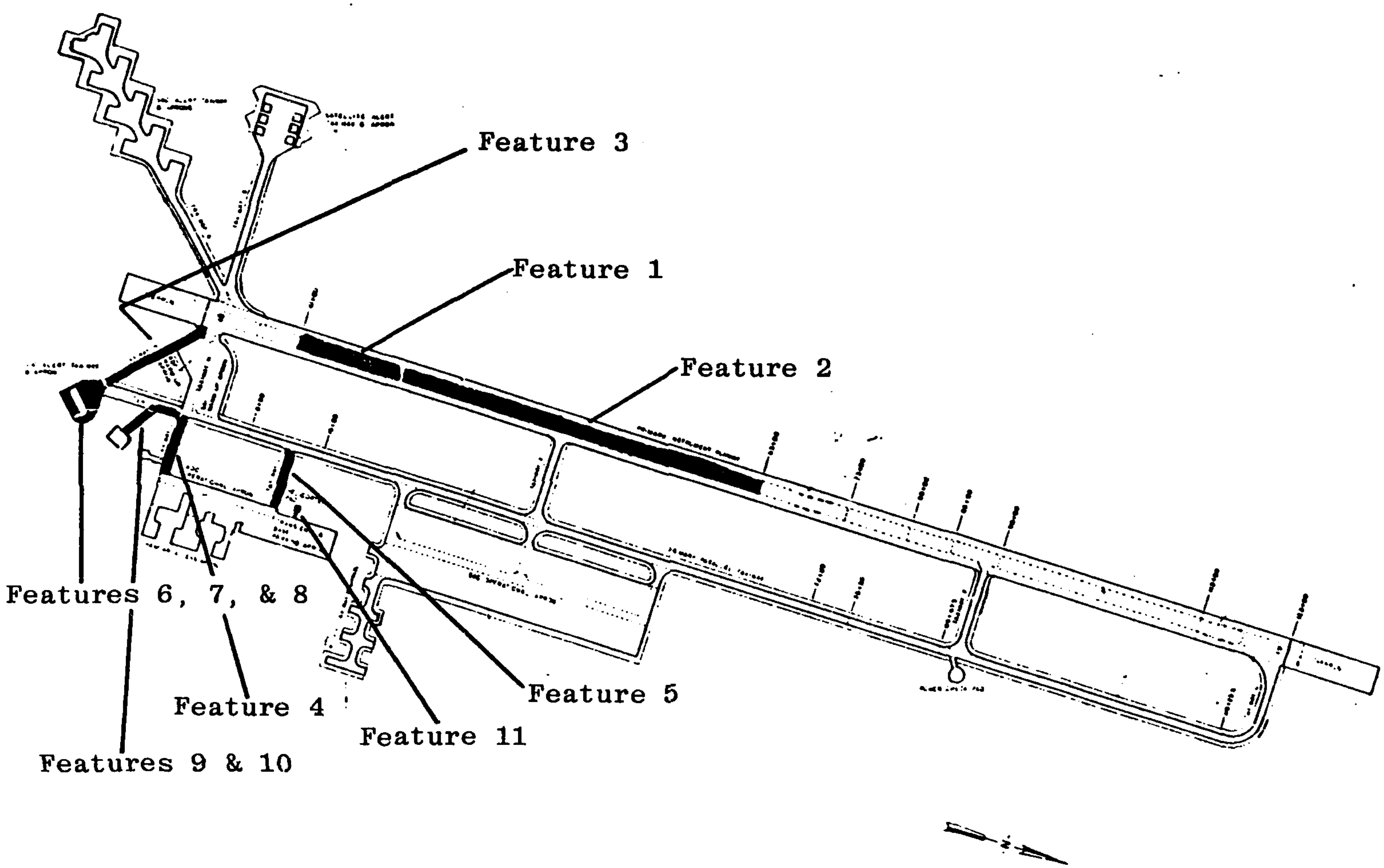


Figure 3-1

Flexible Pavement Features Surveyed at K.I. Sawyer AFB MI

surveyed represent all flexible airfield surfaces that normally receive traffic. Features such as shoulders and overruns were not studied.

K.I. Sawyer AFB was selected as the data gathering site because it was the closest base to Wright-Patterson AFB with a significant amount of flexible pavement that had not been previously surveyed. Also, the Base Civil Engineer was willing to support a data gathering effort. All data was collected during the period of 16 through 20 June 1983.

Data collection efforts concentrated primarily on the data which is needed for the current CERL flexible pavement prediction model. This data included: the actual Pavement Condition Index of each feature, feature age, thickness of the original pavement, thickness of any overlay, construction history, base course and subgrade California Bearing Ratio (CBR) values, aircraft traffic data for each feature, and environmental information.

Pavement Condition

The present PCI of the asphalt pavement at K.I. Sawyer AFB was determined in accordance with AFR 93-5, Chapter 3. Each feature was divided into sample units of approximately 5000 square feet. The distresses present in each sample were recorded using an Air Force Form 1896, PCI Calculation Sheet (17:p.3-42). The distresses in each sample were totalled by distress type and severity level.

The summarized distress information was then entered into the Air Force Logistics Command's Pavement Condition Index computation program available on the CREATE computer system. The PCI program is based on the density versus deduct value curves in AFR 93-5. Once all data was entered into the computer, a PCI was generated for each feature, along with summary information on the distresses and severity levels present in that feature. Appendix A contains the output from the PCI computation program for each feature.

Pavement Construction Information

Data such as age, thicknesses of pavement and base course material, and construction history were obtained from the as-built drawings maintained by the K.I. Sawyer AFB Base Civil Engineer. The most recent Airfield Pavement Evaluation Report was used as the source of base and subgrade CBR data; it was also used to verify the construction information found in the drawings.

Aircraft Traffic

The number of passes per aircraft type, over each feature, is required to compute the mechanistic variables used in the present PCI prediction model for flexible pavement. However, accurate data on past aircraft traffic has been found to be very difficult, if not impossible, to obtain in other studies, due to a lack of record keeping (1:83; 13:6). The engineers at CERL used subjective estimates

of aircraft traffic when no accurate data could be found, because "even subjective estimates were considered to be better than no estimate at all [13:6]."

The traffic data for the 11 features surveyed at K.I. Sawyer AFB came from several sources. The current traffic data (i.e., since January 1982) was obtained from the 410th Bombardment Wing Base Operations personnel. The data provided was very complete, because good records were maintained for the current year (calendar year 1983) and the previous year (1982). Due to the limited number of taxiways and the single runway, it was possible for Base Operations personnel to identify the traffic patterns of each type of aircraft. The activities of the 87th Fighter Interceptor Squadron (FIS), flying the F-106s and T-33s stationed at K.I. Sawyer AFB, were not available at Base Operations because most of their operations were local and did not require a flight plan. The 87th FIS scheduler was able to provide complete sortie information since 1982.

Older aircraft traffic data was somewhat more difficult to obtain. Fortunately, K.I. Sawyer AFB is a relatively new base (operations began in 1956) and has had no major mission changes since 1962. Even the type and number of aircraft assigned have remained nearly constant, except for a conversion from F-101 to F-106 fighters in 1972. Also, one of the early base pavement engineers (1959-1963) maintained a yearly aircraft traffic count, including most

transient aircraft. This traffic data was maintained with the as-built drawings as part of an early pavement maintenance plan. The same engineer that recorded the early traffic counts was the Deputy Base Civil Engineer at the time of the data gathering trip and so was available to answer any questions. Such accurate traffic counts, this old, are probably rare at other Air Force bases.

Intermediate traffic data was found in the 1975 Airfield Pavement Evaluation Report and in a 1979 Airfield Pavement Condition Survey Report prepared by the base for the Strategic Air Command.

One last event aided the accuracy of the aircraft traffic data for several of the features. These features were totally reconstructed in 1981. This meant that the very accurate data maintained by Base Operations provided an almost exact traffic count over these newer features.

Several other sources of information provided verification of the traffic data. The Deputy Base Civil Engineer, having been on station since 1959 and having served as the base pavement engineer, had a very good knowledge of general traffic levels and construction history. The Chief of Base Operations provided a pilot's view of aircraft traffic patterns, as he was a B-52 pilot who had been on station for 13 years. Interviews with the 87th FIS maintenance personnel provided traffic flows on the newly constructed taxiway

leading to an engine sound suppression chamber called the "hush house."

The aircraft traffic was broken down into missions based on a feature's construction history. For example, the asphalt portion of the runway was broken into two mission periods. Period one included all traffic on the feature from 1956 (year of construction) to 1965 (year of last overlay). The second period included all traffic since 1965. Several of the features at K.I. Sawyer AFB had only one traffic period because they were reconstructed from the base course up in 1981.

Transient aircraft were considered as a group, rather than by each type of aircraft, because of the small numbers involved. Each type of transient aircraft was placed in one of four group depending on their equivalent single wheel load (ESWL) and tire pressure (p). The equivalent single wheel load of an aircraft is the load imposed on the pavement by a single wheel that has the same effect (i.e., stress and/or deflection) as the main gear wheel group. The four categories shown in Table 3-1 were determined by the CERL engineers to adequately group aircraft by their effect on flexible pavement (13).

A summary of aircraft types using K.I. Sawyer AFB and the years they were active is shown in Table 3-2.

TABLE 3-1

Aircraft Loading Types for Flexible Pavement (13)

A/C Loading Type	ESWL (kips)	Tire Pressure (psi)
A	ESWL < 75	p < 140
B	ESWL < 75	140 < p < 225
C	ESWL > 60	p > 225
D	ESWL < 60	p > 225

TABLE 3-2

Aircraft Assignment Summary for K.I. Sawyer AFB

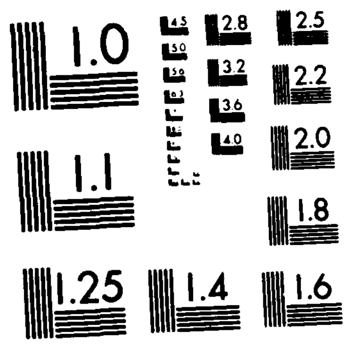
Aircraft	Years Assigned From	To
B-52	1961	Present
KC-135	1960	Present
F-101	1959	1972
F-106	1972	Present
T-33	1959	Present
T-37	1977	Present
C-47	1956	1972
F-102	1957	1959
H-43	1962	1975

Environmental Data

Environmental information required for the flexible pavement PCI prediction model included the mean annual solar radiation, air temperature, and precipitation. The mean annual air temperature and precipitation were obtained from

AD-A134 390 AN EVALUATION OF THE PAVEMENT CONDITION INDEX PREDICTION MODEL FOR FLEXIB..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. J D LYON 2/2

UNCLASSIFIED SEP 83 AFIT-LSSR-11-83 F/G 5/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

the most recent Pavement Evaluation Report for K.I. Sawyer AFB. The mean annual solar radiation was obtained from charts maintained at CERL.

Mechanistic Variables

Some of the collected raw data was input into computer programs to determine the mechanistic variables used in the prediction model. These mechanistic variables, defined previously in Equation (2-7), are ADAV and VCR. The mechanistic variables used to compute ADAV and VCR (i.e., AD, AV, and σ_v) were computed using output from the computer program BISAR. BISAR (Bitumen Structures Analysis in Roads) was developed by Shell Oil Company to analyze elastic layered pavement systems under various loadings. BISAR uses several raw variables known to effect a pavement system's ability to carry load. These raw variables are: initial asphalt thickness, overlay thickness, total asphalt thickness, base course thickness, and subgrade CBR. Several additional variables used in the computer output need to be defined. They are A, D, and CVS. These variables were used in the data base to compute ADAV.

ADAV = AD x AV

AD = D/A

D = surface deflection divided by ESWL

A = total aircraft passes

$AV = CVS/A$

CVS = vertical stress on top of base course

Other variables used in the BISAR program were found using the tables and graphs in the appendices of a draft CERL study entitled "Development of a Pavement Maintenance Management System, Volume IX: Airfield Pavement Condition Prediction Models" (13). These variables included: aircraft ESWL, Young's modulus for asphalt (E_{ac}), Young's modulus for the base course (E_{gr}), and Young's modulus for the subgrade (E_{sub}).

Using Figure 3-2, the asphalt half-thickness and mean annual solar radiation were used to find a temperature increment, Δ, in degrees Fahrenheit. The temperature increment was then added to the mean annual air temperature, T_{air}, to compute the pavement temperature, T_{pave} (13). The Young's modulus for asphalt, E_{ac}, was then determined using Figure 3-3. The Young's modulus for the base course, E_{gr}, was determined from Figure 3-4 as a function of pavement thickness, E_{ac}, and aircraft loading type (Ref. Table 3-1).

Using the Federal Aviation Administration (FAA) soil classification system, the subgrade at K.I. Sawyer AFB graded as an E-4 material or a poorly graded sandy soil (19:234). From Table 3-3, soil group E-4 corresponds to the FAA subgrade class of F1 for soils with good drainage (19:466). The E_{sub} was then approximated using Table 3-4. This approximation method was used because the standard technique

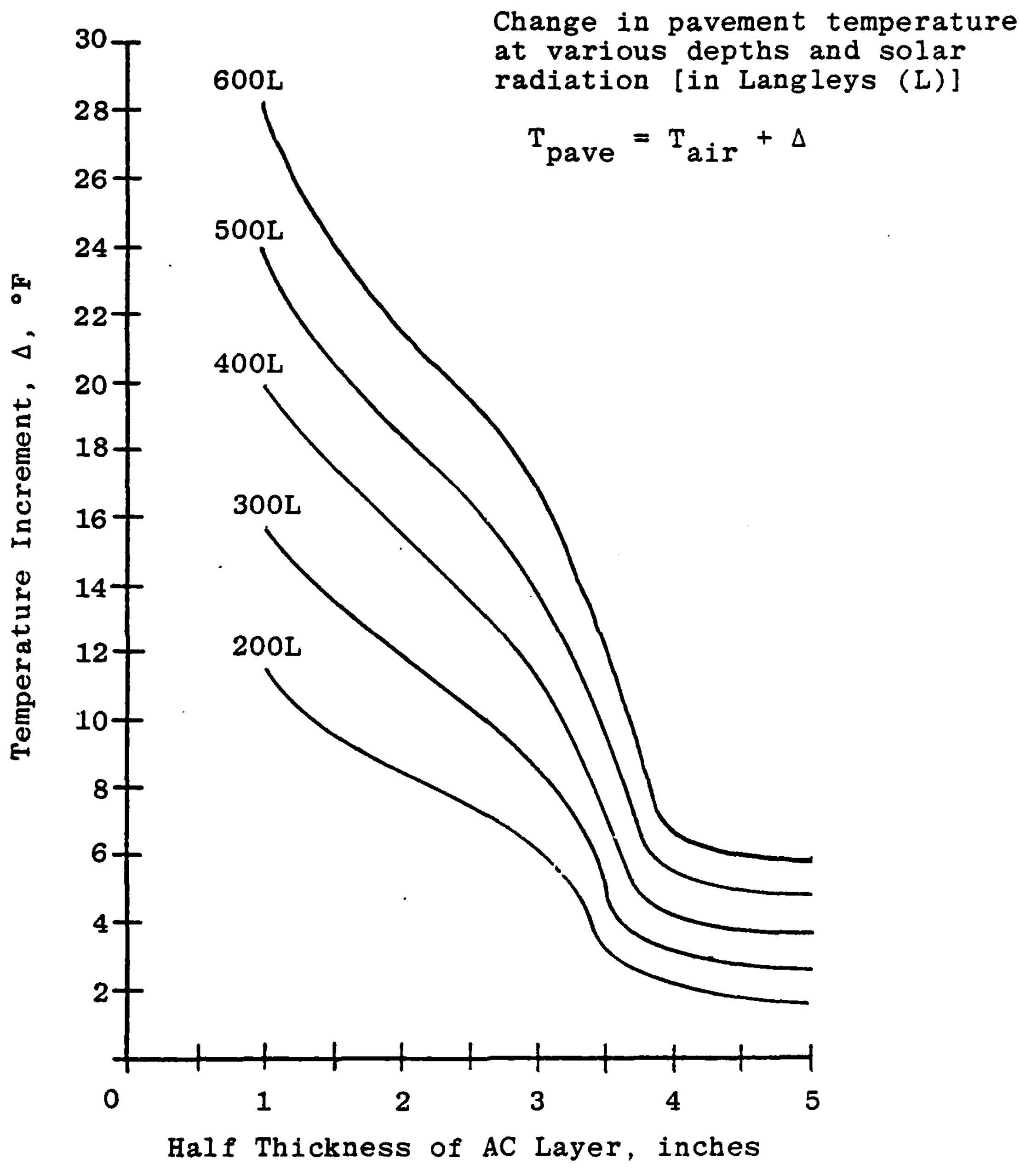


FIGURE 3-2

Determination of Temperature Increment (13)

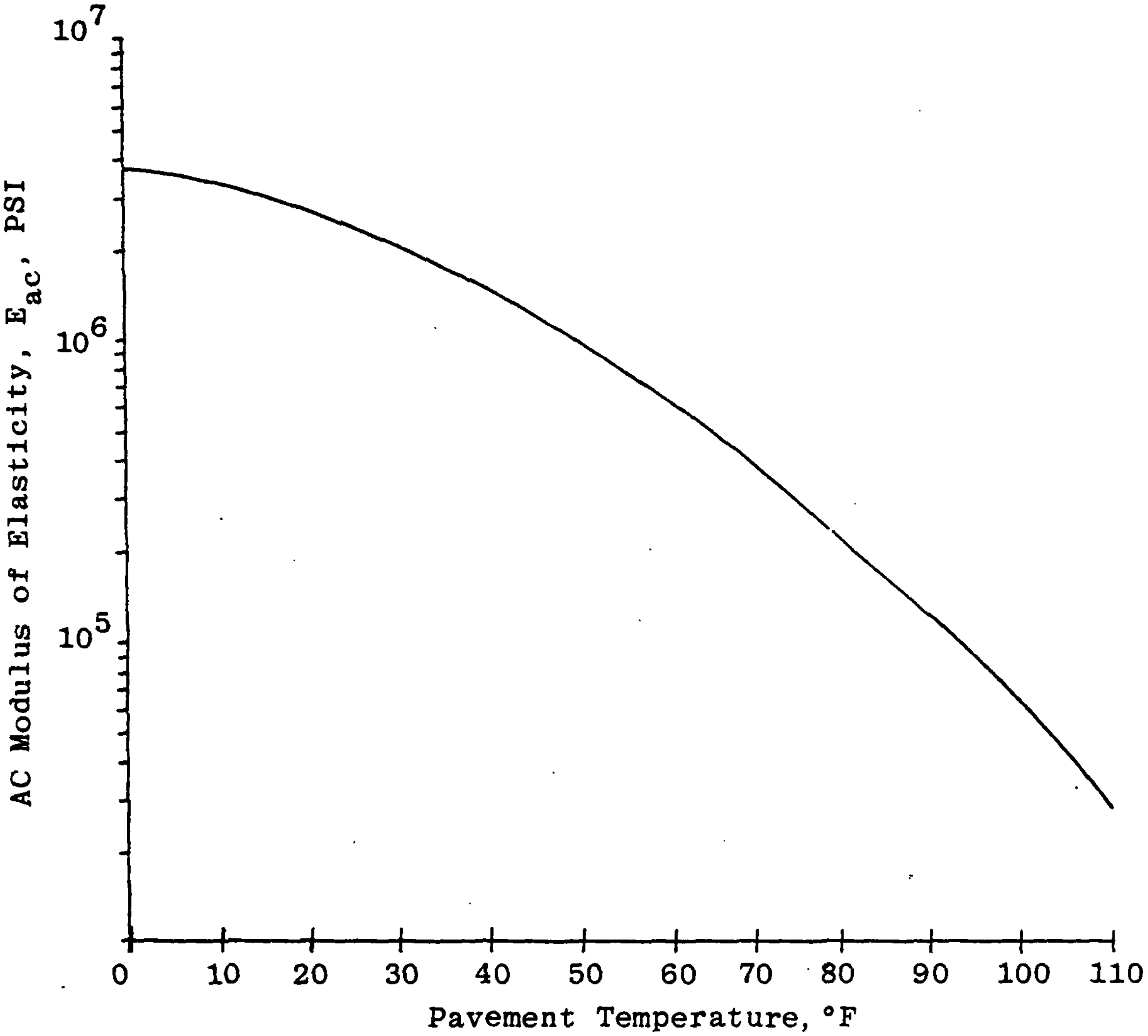
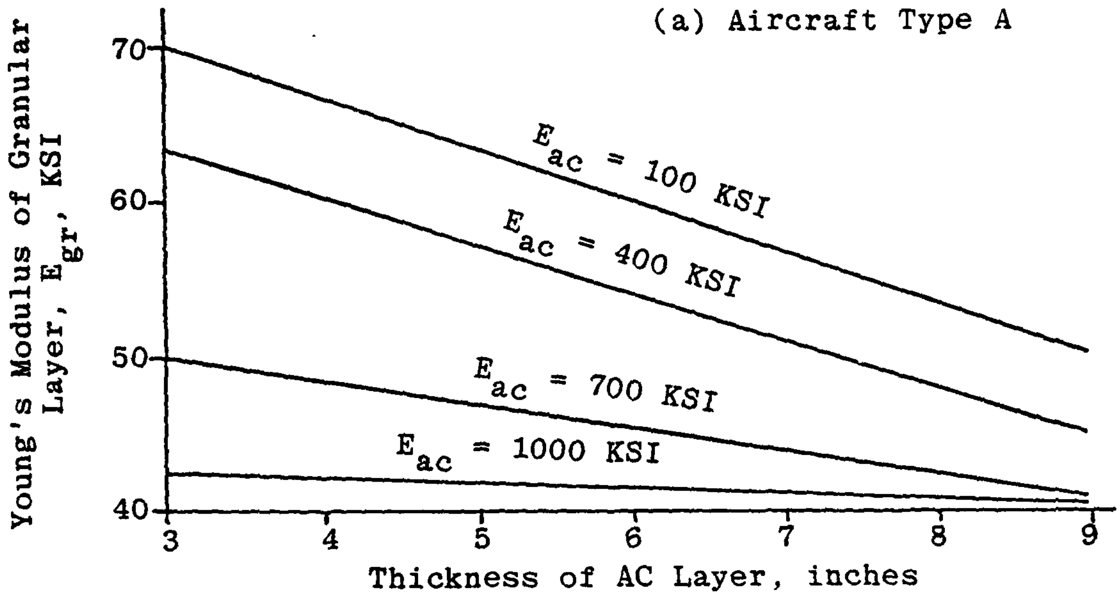


FIGURE 3-3

Variation of AC Modulus of Elasticity
versus Pavement Temperature



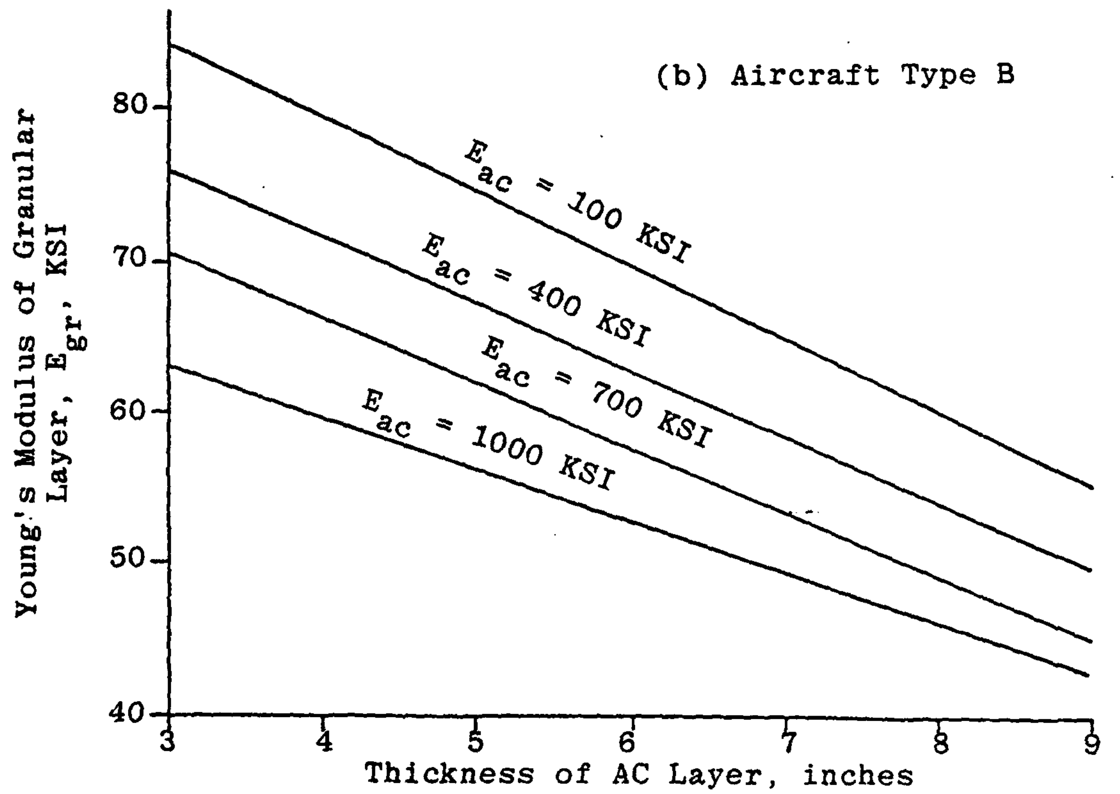
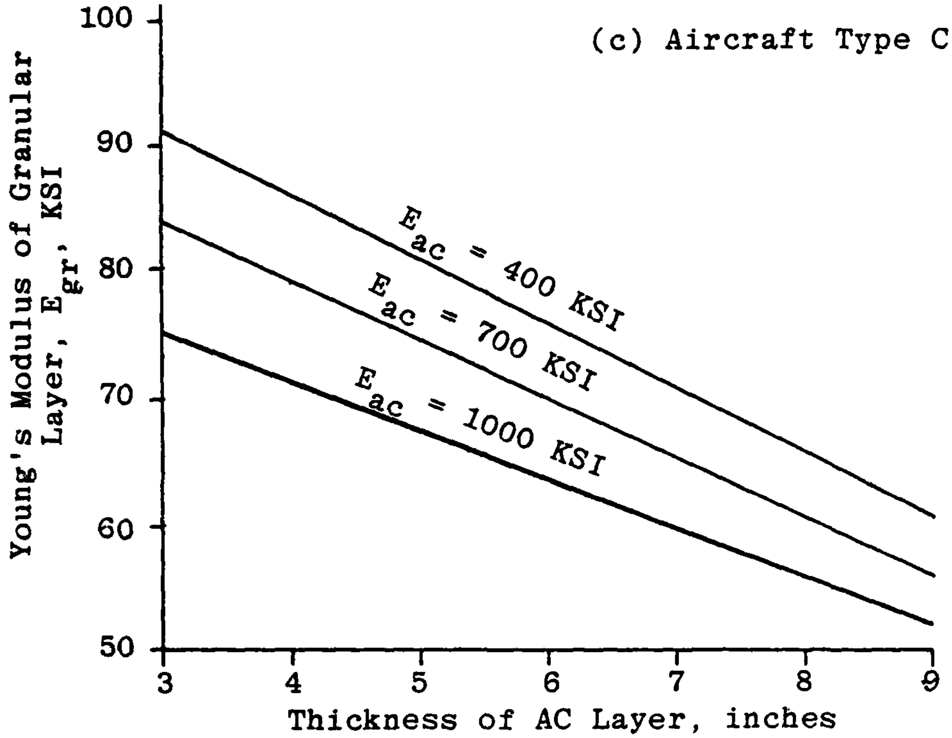


FIGURE 3-4

Young's Modulus of Granular Layers in Asphalt Pavement for Various Aircraft Types (13)



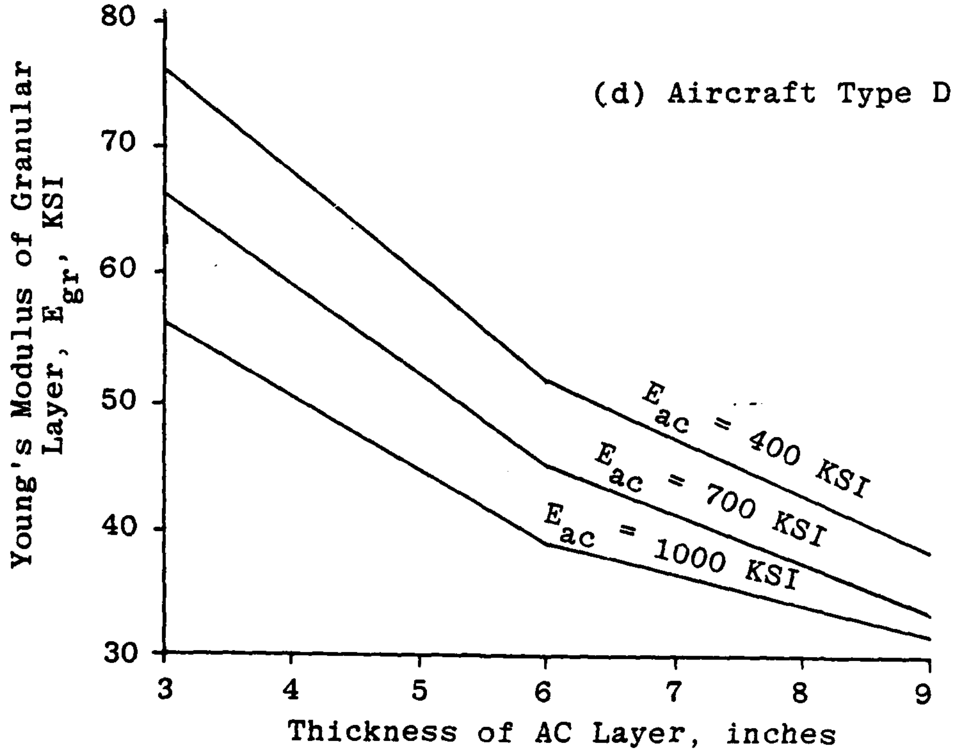


FIGURE 3-4 (Continued)

TABLE 3-3

FAA Subgrade Classes for Flexible Pavements
[19:466]

FAA Soil Classification	Subgrade Class: Good Drainage, No Frost	Good Drainage, Frost	Poor Drainage, No Frost	Poor Drainage, Frost
E-1	Fa	Fa	Fa	F1
E-2	Fa	Fa	F1	F2
E-3	F1	F1	F2	F3
E-4	F1	F1	F2	F4
E-5			F3	F5
E-6			F4	F6
E-7			F5	F7
E-8			F6	F8
E-9			F7	F9
E-10			F8	F10
E-11			F9	F10
E-12			F10	F10
E-13			Unusable	Unusable

TABLE 3-4

Young's Modulus Approximation

FAA Classification	E (psi)
F10	5,500
F9	6,500
F8	7,700
F7	8,900
F6	10,800
F5	12,600
F4	14,600
F3	16,600
F2	19,900
F1	22,700
Fa	31,000

used by CERL (E_{sub} = CBR x 1500) was felt to be better suited for cohesive soils than cohesionless soils.

Using Young's modulus, Poisson's ratio (assumed to be 0.35), layer thickness, and the ESWL for each layer in the pavement system (asphalt, base, and subgrade), the BISAR program computed a vertical stress and surface deflection. The weighted average mechanistic variables AD, AV, and σ_v were then computed using the vertical stress and surface deflection for each type of aircraft and each pavement system. (13)

Predicted PCI Values

The Pavement Condition Index was calculated for each of the 11 features surveyed at K.I. Sawyer AFB using the current linear model for predicting the PCI on flexible pavement. The raw variables of pavement age, average annual precipitation, and thickness of the pavement were used together with the mechanistic variables of vertical deflection, ESWL, and vertical stress in Equation (2-7) to predict the PCI.

$$PCI = 96.817 - 7.0733(ADAV)(AGE) - 0.00050865(VCR)(AGE) - 0.048290[(PRECI)(AGE)/(THICK)] \qquad (2\text{-}7)$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

ADAV = AD x AV

AD = weighted average surface deflection divided by ESWL (kips)

AV = weighted average vertical stress on top of base course (psi)

AGE = age of pavement since construction or, if overlaid, since overlay construction

$$VCR = \sqrt{\sum_{i=1}^{a} (\sigma_v)(N)}$$

a = number of different aircraft

σ_v = stress on top of base course before most recent overlay

N = number of passes of aircraft before most recent overlay

PRECI = mean annual precipitation, inches

THICK = thickness of the AC layer most recently constructed

Table 3-5 is an example of how to calculate the PCI using the prediction model (Equation (2-7)).

Analysis

An analysis was done to compare the PCI values predicted by Equation (2-7) to the actual PCI values of the features surveyed. Using the SPSS subroutine SCATTERGRAM, a plot was produced with the actual PCI on one axis and the predicted PCI on the other. Any linear relationship between the two variables could be seen on the plot and was quantified using the Pearson correlation coefficient.

The Pearson correlation coefficient is a measure of the strength of the linear relationship between the two

TABLE 3-5

An Example Calculation of the PCI for a Flexible Airfield Pavement Feature (13:48)

A. DATA INPUT:

Aircraft	C141, F4
Passes/Year	3000/C141, 5000/F4
Initial Asphalt Thickness	3 inches
Age Before Overlay	15 years
Overlay Thickness	2 inches
Total Asphalt Thickness	5 inches
Base Thickness	12 inches
Subgrade CBR	10
Age Since Overlay	20 years
Solar Radiation	400 Langleys
Mean Air Temperature	50 degrees F
Precipitation	30 inches
ESWL	58.97 kips/C141; 25.48 kips/F4

B. DATA GENERATED FROM BISAR PROGRAM

	Before Overlay (3" AC Thickness)	After Overlay (5" AC Thickness)
F4		
Surface Deflection	0.0484 inches	0.0379 inches
Vertical Stress on Base	173.2 psi	96.75 psi
C141		
Surface Deflection	0.0983 inches	0.0834 inches
Vertical Stress on Base	235.7 psi	154.9 psi

C. SOLUTION

Compute ADAV:

$$ADAV = AD \times AV$$

$$AD = \frac{\left(\frac{Deflection}{ESWL} \times \frac{Passes}{Yr}\right) \times Yrs + \left(\frac{Deflection}{ESWL} \times \frac{Passes}{Yr}\right) \times Yrs}{\Sigma(Passes/Yr \times Yrs)}$$

$$AD = \frac{\left(\frac{0.0379}{25.48} \times 5000 \times 20\right) + \left(\frac{0.0834}{58.97} \times 3000 \times 20\right)}{(5000 \times 20) + (3000 \times 20)}$$

$$AD = 1.4599 \times 10^{-3}$$

$$AV = \frac{(\sigma_v \times Passes/Yr \times Yrs) + (\sigma_v \times Passes/Yr \times Yrs)}{\Sigma(Passes/Yr \times Yrs)}$$

$$AV = \frac{(96.75 \times 5000 \times 20) + (154.9 \times 3000 \times 20)}{(5000 \times 20) + (3000 \times 20)}$$

$$AV = 118.55$$

$$ADAV = (1.4599 \times 10^{-3})(118.55) = 0.17308$$

Compute VCR:

$$VCR = \sqrt{\sum_{i=1}^{a} (\sigma_v)(N)}$$

$$= \sqrt{(173.1 \times 15 \times 5000) + (235.7 \times 15 \times 3000)}$$

$$= 4872$$

TABLE 3-5 (Continued)

Compute PCI:

$$PCI = 96.817 - 7.0733(ADAV)(AGE) - 0.00050865(VCR)(AGE) - 0.048290(PRECI)(AGE)/THICK$$

$$PCI = 96.817 - 7.0733(0.17308)(20) - 0.00050865(4872)(20) - 0.048290(30)(20)/2$$

$$= 96.817 - 24.485 - 49.563 - 14.487$$

$$= 8 \text{ FAILED CONDITION}$$

variables being compared. A coefficient of plus one indicates a perfect positive linear correlation and the SCATTERGRAM plot should appear as a straight line starting at the origin, with a slope of one. A coefficient of minus one indicates a perfect negative correlation and a value of zero means no relationship at all. (6:59) Based upon the results of the SCATTERGRAM, inferences can be made about the ability of the PCI prediction model to predict the PCI of the population of all flexible pavements. SCATTERGRAM was also used to determine the bivariate regression statistics, including the regression coefficient (the slope) and the constant (the intercept) (6:92-93).

After determining the ability of the present flexible model to predict the PCI, the new data was combined with the data used to develop the prediction model, to determine the effect on the model. The SPSS REGRESSION subprogram was run on the combined data set and a modified model was built. The REGRESSION package makes it possible to determine the relationship between a dependent variable and several independent variables (6:91). Using the Stepwise procedure, each variable was entered into the model in the order of its significance, as determined by the partial F-test. After each new variable was added, the computer rechecked all previously entered variables to ensure that they were still significant. Only variables with a

significance of 0.05, as determined by the F-test, were entered. (6:120-121)

The next step was an attempt to improve the ability to predict the PCI in flexible pavements. The model developed by CERL was based on the assumption that a linear relationship exists between the dependent variable, PCI, and the independent variables. To improve the model, various linear and nonlinear combinations of variables were analyzed. Again, the SPSS REGRESSION package was used for all data analyses. Using the newly created variables, a new prediction model was built and its validity checked. The Stepwise procedure for adding variables into the model was again used, with each variable entered at a significance level of 0.05 using the partial F-test.

Finally, the SPSS REGRESSION package was used on only the K.I. Sawyer AFB data, to see if a model could be built that better explains the variation in the PCI at that base than any general model yet derived.

Assumptions and Limitations

It is assumed that only the variables found in the present PCI prediction model (Equation (2 - 7)), and the variables required to compute those variables, are significant. This assumption is based on the research done by CERL, which after screening over 50 pavement variables, found

only the ones in Equation (2 - 7) to be significant in predicting the PCI of flexible pavement.

It is also assumed that the pavement condition survey performed by the author at K.I. Sawyer AFB is within plus or minus five points of the results of a survey done by any other person experienced with the PCI condition survey. Consistent results among different engineers using the PCI condition survey have been established by CERL (9:121).

CHAPTER 4

FINDINGS AND ANALYSIS

The purpose of this chapter is to summarize the results of the statistical evaluation of the current linear Pavement Condition Index prediction model for flexible pavements. The chapter also summarizes the efforts to improve upon that model. The analysis considers each of the research questions as presented in Chapter 1. Additional analyses or observations are presented when appropriate.

New Data Base

CERL developed the current linear PCI prediction model for flexible pavement (i.e., Equation (2-7)) using 70 flexible pavement features surveyed from 1977 to 1979 (13:2). In order to evaluate the model CERL presented, it was necessary to gather data on flexible pavement features not included in the original data base. To evaluate the current model, 11 flexible pavement features were surveyed at K.I. Sawyer AFB MI. A pavement condition survey was done in accordance with Air Force Regulation 93-5 to determine the actual PCI. A summary of the types, severity levels, and densities of the pavement distresses for each feature is contained in Appendix A.

Aircraft traffic data was gathered to provide input for a computer stress analysis for each feature surveyed. Table 4-1 contains a summary, by feature, of aircraft type, the number of passes per year, and the years each feature was used by each aircraft type.

Transient aircraft passes are significant as a whole, but because of the wide variety, the passes by individual aircraft types were often small in number. To prevent having to work with such a large number of aircraft with so few passes, all transients were grouped into one of the four categories listed in Table 3-1 and the passes and loads were averaged for each category.

Other collected data included construction characteristics, history, and environmental data on each feature. The raw and computer generated mechanistic data for each feature surveyed is summarized in Table 4-2. The data obtained from CERL on the 70 original features and the data gathered at K.I. Sawyer AFB are listed in Appendices B and C, respectively.

Prediction Model Evaluation

The first step in evaluating the current flexible pavement PCI prediction model was to use the U.S. Army data and attempt to duplicate their results. The SPSS REGRESSION program was run using the same variables and the data from the 70 flexible features used to develop the current model.

TABLE 4-1

Aircraft Traffic Summary for K.I. Sawyer AFB

Feature	A/C Type	Current Period passes/yr	Current Period no. years	Previous Period passes/yr	Previous Period no. years
		1965—1983		1956—1965	
1	B-52	1984	18	2086	5
	KC-135	2080	18	2582	6
	F-101	4331	7	5372	7
	F-106	5359	11	0	0
	F-102	0	0	7000	2
	T-33	1824	18	2152	10
	T-37	919	7	0	0
	C-47	3327	7	2280	10
	Transient A	933	18	1180	10
	Transient B	389	18	250	3
	Transient D	752	18	100	10
2	B-52	1984	18	2086	5
	KC-135	2080	18	2582	6
	F-101	4331	7	5372	7
	F-106	5359	11	0	0
	F-102	0	0	7000	2
	T-33	1824	18	2152	10
	T-37	919	7	0	0
	C-47	3327	7	2280	10
	Transient A	933	18	1180	10
	Transient B	389	18	250	3
	Transient D	752	18	100	10

TABLE 4-1 (Continued)

Feature	A/C Type	Current Period passes/yr	Current Period no. years	Previous Period passes/yr	Previous Period no. years
		1981—1983		None	
3	F-106	416	2		
4	F-106	3710	2		
	T-33	968	2		
5	F-106	3710	2		
	T-33	968	2		
	T-37	1370	2		
	Transient A	933	2		
	Transient B	389	2		
	Transient D	752	2		
6	F-106	312	2		
7	F-106	416	2		
8	F-106	52	2		
		1982—1983		1957—1981	
9	F-106	2	1	0	0
	F-102	0	0	7000	2
	F-101	0	0	416	10

TABLE 4-1 (Continued)

Feature	A/C Type	Current Period passes/yr	Current Period no. years	Previous Period passes/yr	Previous Period no. years
	T-33	0	0	500	10
	C-47	0	0	500	10
10	F-106	2	1	0	0
		1960—1983		None	
11	H-43	1000	13	0	0

TABLE 4-2

Summary of Data Collected at K.I. Sawyer AFB

Variable	Mean	Standard Deviation	Range
ACTPCI	79.636	22.509	43-100
AGE (years)	6.455	8.104	1-21
A (passes)	51,421	104,431	2-262,320
D (in. x 10)	48.183	89.980	0.002-241.090
CVS	1,734,689	3,394,037	86-8,912,900
VCR	2,314,255	4,280,163	0-10,600,000
PRECI (inches)	32.9	0	32.9-32.9
THICK (inches)	3.159	0.551	2.0-4.0
AD	0.002	0.001	0.001-0.003
AV	57.427	20.116	31.375-81.2
ADAV	0.092	0.044	0.028-0.135
AGE x ADAV	0.423	0.579	0.053-2.111
AGE x VCR	10,829	23,589	58,609
PRAGET*	76.312	109.46	10.967-345.45

*PRAGET = (AGE)(PRECI)/THICK

The CERL results could not be duplicated. The coefficient of determination, R squared, was 0.39 and the regression constant was approximately 86, compared to 0.70 and 96, respectively, reported by CERL. Further research revealed that in order to achieve the current flexible model, CERL added 70 additional features with PCIs of 100 and ages of zero to the original 70 features to improve the results (5). The added data was based on the assumption that each feature had a PCI of 100 when age was zero. The additional 70 features had the effect of introducing false degrees of freedom to the analysis, forcing the R squared and regression constant to increase to the levels reported by CERL. This is not a recommended statistical practice (18). Once data from the additional 70 features were added to the original data, duplication of the CERL model became possible.

Rather than continue evaluating a model based on a questionable statistical technique, it was decided to rerun the analysis of the original 70 data features and force the regression through the origin. This technique is statistically acceptable whenever the constant of the regression is known ahead of time. In this case, since all variables are multiplied by age, it is known that when flexible pavement is new (AGE=0), then the PCI will equal 100.

When the regression is forced through the origin, the R squared is no longer a direct measure of the amount of the variation in the PCI that is explained by the model.

However, the R squared can still be used to compare different models that are all forced through the origin. (18)

A stepwise regression analysis was run using the original CERL data and variable combinations (Ref Appendix D). The regression was forced through the origin and resulted in the following model:

$$PCI = 100 - 0.0567769(PRECI)(AGE)/THICK - 7.58168(AGE)(ADAV) - 0.00055733(AGE)(VCR) \quad (4\text{-}1)$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

PRECI = mean annual precipitation, inches

AGE = age of pavement since construction or, if overlaid, since overlay construction

THICK = thickness of the AC layer most recently constructed

ADAV = AD x AV

AD = weighted average surface deflection divided by ESWL (kips)

AV = weighted average vertical stress on top of base course (psi)

$$VCR = \sqrt{\sum_{i=1}^{a} (\sigma_v)(N)}$$

a = number of different aircraft

σ_v = stress on top of base course before most recent overlay

N = number of passes of aircraft before most recent overlay

Equation (4-1) had an adjusted R squared of 0.80 and a standard deviation of 14.15. This equation then became the basis for the remainder of the evaluation of this research.

Original Model Evaluation

A scattergram of the PCI predicted by Equation (4-1) for the 11 features surveyed at K.I. Sawyer AFB and the actual PCIs for those features is shown in Figure 4-1. All points would plot on line a-a if the model was perfectly capable of predicting the PCI without error. Line a-a has a slope of one and an intercept of zero. (6:63) The line that best fits the data in this case has a slope of 0.83 and an intercept of 20.15.

The strength of the linear relationship between the predicted and actual PCIs can be determined using the Pearson's correlation coefficient, r. The Pearson's r is computed as part of the SPSS SCATTERGRAM program. When the coefficient is equal to 1.0, there exists a perfect positive linear relationship, a value of -1.0, indicates a perfect negative linear relationship. A Pearson's r of zero indicates that no linear relationship exists at all. (3:520-521) The Pearson's r for Equation (4-1) was 0.98, which indicates a very strong positive linear relationship between the predicted PCI and the actual PCI.

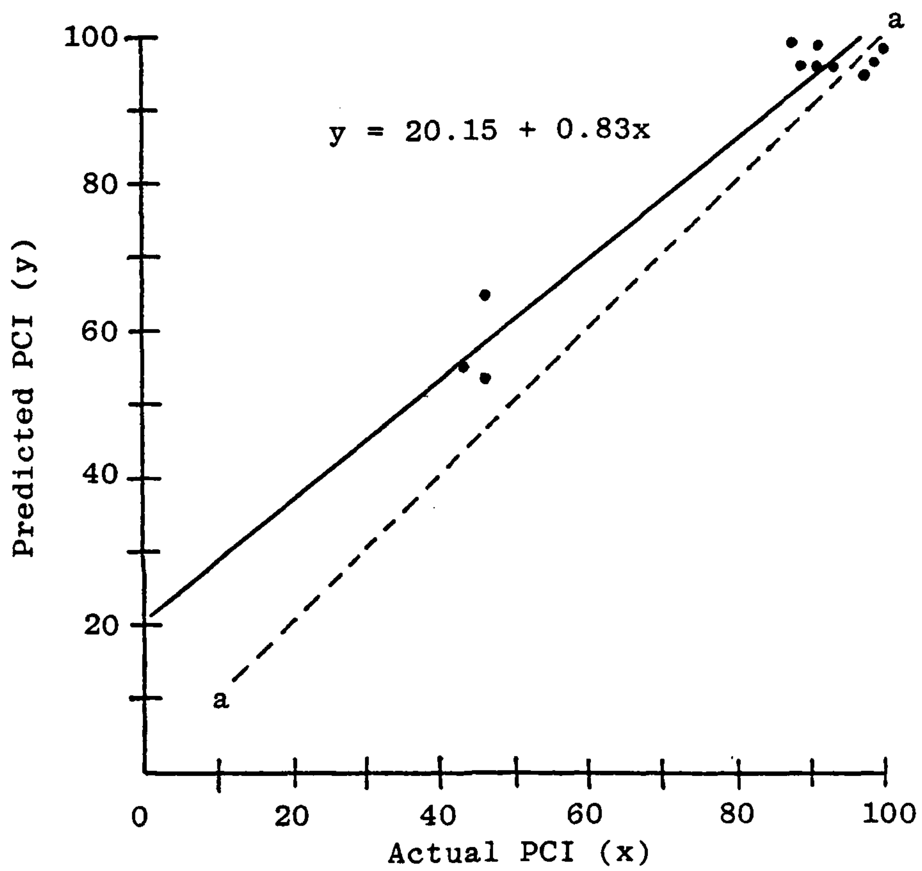


FIGURE 4-1

Scattergram of Actual versus Predicted PCI Values for the Original PCI Prediction Model Forced Through the Origin

Two conclusions can be drawn from the evaluation of Equation (4-1) and the current CERL model, Equation (2-7). First, neither model is capable of predicting the actual pavement condition for the 11 features at K.I. Sawyer AFB. This is particularly true for pavement in poor condition. For example, a pavement having a PCI of 20, or very poor condition, would have a predicted PCI of 37, using Equation (4-1). Second, the statistical technique of forcing the regression through the origin, as was done for Equation (4-1), actually improved the ability to predict the PCI of the flexible pavement features at K.I. Sawyer AFB.

Modified Prediction Model

The next step in this analysis was to add the data on the 11 features surveyed at K.I. Sawyer AFB to the data from the original 70 features obtained from CERL, and rerun the regression analysis (Ref Appendix E). The regression of the combined data was forced through the origin and resulted in the following model:

$$PCI = 100 - 0.06262(PRECI)(AGE)/THICK$$
$$-7.4773(AGE)(ADAV) - 0.0005679(AGE)(VCR) \qquad (4\text{-}2)$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

PRECI = mean annual precipitation, inches

AGE = age of pavement since construction or, if overlaid, since overlay construction

THICK = thickness of the AC layer most recently constructed

ADAV = AD x AV

AD = weighted average surface deflection divided by ESWL (kips)

AV = weighted average vertical stress on top of base course (psi)

$$VCR = \sqrt{\sum_{i=1}^{a} (\sigma_v)(N)}$$

a = number of different aircraft

σ_v = stress on top of base course before most recent overlay

N = number of passes of aircraft before most recent overlay

All variables from the original model (i.e., Equation (4-1)) continued to be significant in Equation (4-2), the modified model. A summary of the combined data base used to develop this model is contained in Table 4-3.

The modified model is an improvement over the original model, forced through the origin (i.e., Equation (4-1)). The same variables continued to be significant, although their coefficients did change slightly. The variables [(AGE)(PRECI)/THICK] and [(AGE)(VCR)] both increased their influence on the PCI, while the variable [(AGE)(ADAV)] lost some influence.

An important measure of the model's strength in predicting the PCI is the coefficient of determination,

TABLE 4-3

Summary of Combined CERL and K.I. Sawyer AFB Data

Variable	Mean	Standard Deviation	Range
ACTPCI	73.284	16.364	31-100
AGE (years)	10.136	8.021	0-27
A (passes)	107,136	192,413	1-932,700
D (in. x 10)	121.747	260.147	0-1,781.8
CVS	9,217,315	21,600,000	0-141,400,000
VCR	6,367,072	15,700,000	0-116,300,000
PRECI (inches)	26.938	13.957	3.8-52.1
THICK (inches)	2.673	1.204	0.8-6.0
AD	0.001	0.001	0-.003
AV	79.386	43.997	0-175.068
ADAV	0.10	0.071	0-0.367
AGE x ADAV	1.250	1.618	0-7.711
AGE x VCR	11,610	17,977	0-75,493
PRAGET*	108.723	101.145	0-416.80

*PRAGET = (AGE)(PRECI)/THICK

R squared. Although the R squared of the regression forced through the origin cannot be directly compared to a normal regression R squared, it is still a measure of how well the model explains the variation in the dependent variable. For this reason the R squared among models forced through the origin can be compared (18).

The modified prediction model (i.e., Equation (4-2)) had an R squared of 0.82, compared to the R squared of 0.80 for the model developed only from the CERL data (i.e., Equation (4-1)). It can then be inferred that the addition of the 11 features from K.I. Sawyer AFB to the original 70 features collected by CERL, improves the ability of the model to explain the variation in the PCI.

Improved Model

Although the modified model (i.e., Equation (4-2)) increases the ability to predict the PCI in flexible pavement, it appears to still have room for further improvement. Within the limits of the data gathered at K.I. Sawyer AFB, new combinations of variables were developed and entered into the regression analysis in an effort to achieve such an improvement. A list of the new variables analyzed is contained in Table 4-4. One of the main purposes of trying these new variable combinations was to explore the possibility of the existence of nonlinear relationships between the independent and dependent variables.

TABLE 4-4

New Variables Created in Developing an Improved PCI Prediction Model

$AGEADA2 = (AGE \times ADAV)^2$
$AGEVCR2 = (AGE \times VCR)^2$
$AGEPRET2 = [(AGE)(PRECI)/THICK]^2$
$AGEADTK = [(AD)(THICK)(AGE)]$
$AD2AGE = (AGE \times AD)^2$
$AGEAV2 = (AGE \times AV)^2$
$AGECVS2 = (AGE \times CVS)^2$
$AGEAD = (AGE \times A \times D)$
$AADA2 = (AGE)(ADAV)^2$
$AVCR2 = (AGE)(VCR)^2$
$APRET2 = (AGE)(PRECI/THICK)^2$
$AADTK = (AGE \times AD \times THICK)$
$AAD2 = (AGE)(AD)^2$
$AAV2 = (AGE)(AV)^2$
$ACVS2 = (AGE)(CVS)^2$

A number of regression analyses were attempted using the new variables and only the original 70 data features collected by CERL. A summary of the data used is contained in Table 4-5. The regression analysis was again forced through the origin (Ref Appendix F). The following model is the best to be found thus far and includes only variables found to be significant to the 0.05 level using the partial F-test:

$$PCI = 100 - 0.0492(PRECI)(AGE)/THICK - 156.129(AADTK) - 0.00057(AGE)(VCR) - 0.00004498(AAV2) \qquad (4\text{-}3)$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

PRECI = mean annual precipitation, inches

AGE = age of pavement since construction or, if overlaid, since overlay construction

THICK = thickness of the AC layer most recently constructed

AADTK = (AGE)(AD)(THICK)

AD = weighted average surface deflection divided by ESWL (kips)

$$VCR = \sqrt{\sum_{i=1}^{a} (\sigma_v)(N)}$$

a = number of different aircraft

σ_v = stress on top of base course before most recent overlay

TABLE 4-5

Summary of Data Gathered by CERL with New Variables

Variable	Mean	Standard Deviation	Range
ACTPCI	72.286	15.153	31-100
AGE (years)	10.714	7.911	0-27
VCR	7,003,943	16,730,000	0-116,300,000
PRECI	26.001	14.808	3.8-52.1
THICK	2.587	1.262	0.8-6.0
ADAV	0.101	0.075	0-0.367
AGE x ADAV	1.380	1.691	0-7.711
AGE x VCR	11,732	17,144	0-75,492
PRAGET*	113.817	99.654	0-416.8
AADTK	0.043	0.053	0-0.227
AAV2	120,477	152,778	0-689,004

*PRAGET = [(PRECI)(AGE)/THICK]

N = number of passes of aircraft before most recent overlay

AAV2 = $(AGE)(AV)^2$

AV = weighted average vertical stress on top of base course (psi)

Equation (4-3) still retains the original variables of [(PRECI)(AGE)/THICK] and [(AGE)(VCR)], although both have a decreased effect on the PCI. The variable [(AGE)(ADAV)] dropped out, as no longer significant and AADTK and AAV2 entered the model.

The presence of AAV2 confirms the suspicion that nonlinear relationships exist between the PCI and some of the factors affecting it. The composition of all the variables in Equation (4-3) confirms that the PCI is a function of several variables interacting together. Interaction among the variables means that the independent variables are not truly independent and any changes in one independent variable will have an effect on the other independent variables as well as the dependent variable (18).

The coefficient of determination for Equation (4-3) increased, indicating a further increase in the amount of the variation in the PCI that is explained by the model. Using the same CERL data, Equation (4-3) has a R squared of 0.84, compared to the R squared of 0.80 for the original model forced through the origin (i.e., Equation (4-1)). It can then be inferred that Equation (4-3) is a better model for predicting the PCI in flexible pavement.

Improved Model Evaluation

To check the validity of Equation (4-3), the model was used to compute the PCIs for the 11 features located at K.I. Sawyer AFB. Those values were then compared to actual PCIs for the 11 features. Figure 4-2 shows the results of the scattergram analysis of the two variables.

A perfect linear relationship between the predicted and actual PCI would have plot along line a-a in Figure 4-2. The improved model (i.e., Equation (4-3)) came much closer to line a-a than the previous models. The slope increased to 0.90 (from 0.83 for Equation (4-1) evaluation) and the intercept was reduced to 13.82 (from 20.15). Both changes were toward line a-a. The Pearson's r continued to indicate a very strong positive linear relationship, with a value of 0.97.

In summary, the improved PCI prediction model for flexible pavement (i.e., Equation (4-3)) is better able to predict the PCI for K.I. Sawyer AFB than the previous models analyzed.

Modified Improved Model

In an attempt to further improve the ability to predict the PCI in flexible pavements, the K.I. Sawyer AFB data was added to the original CERL data and a regression analysis (Ref Appendix G) was again run. The same variables

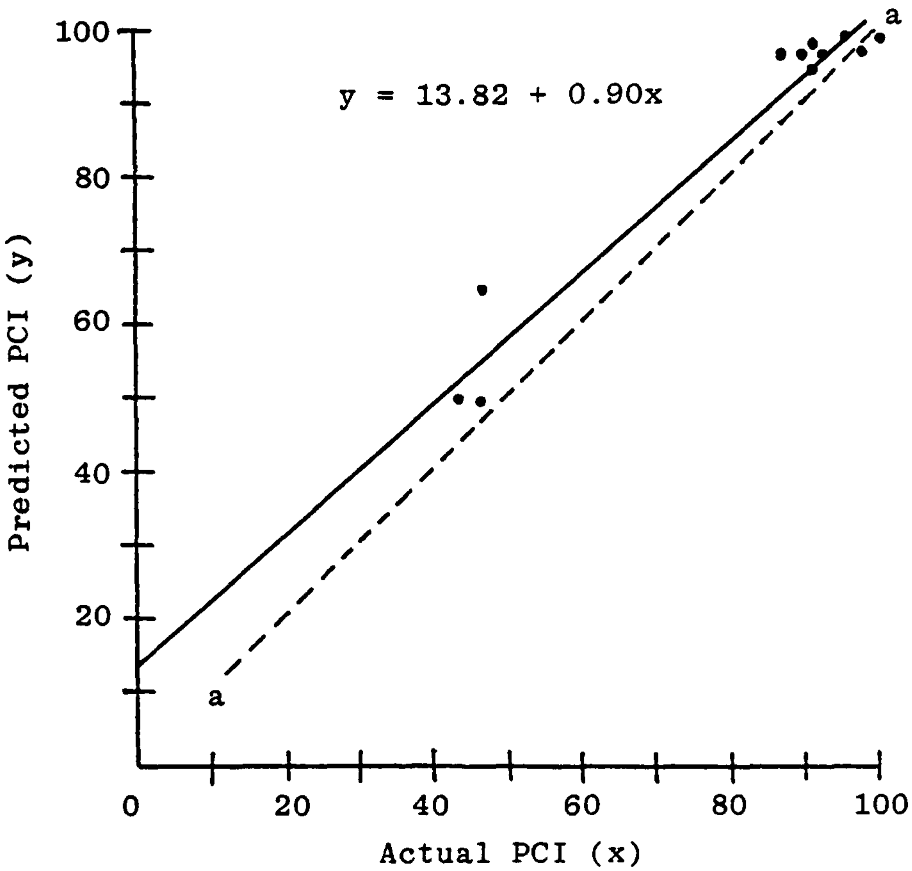


FIGURE 4-2

Scattergram of Actual versus Predictive PCI Values for the Improved PCI Prediction Model

listed in Table 4-4 were used, along with the original variables. Only those variables which proved significant to the 0.05 level using the partial F-test were entered into the equation. The regression analysis resulted in the following modified improved model:

$$PCI = 100 - 0.0546(PRECI)(AGE)/THICK - 172.151(AADTK) - 0.000565(AGE)(VCR) - 0.0000385(AAV2) \quad (4\text{-}4)$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

PRECI = mean annual precipitation, inches

AGE = age of pavement since construction or, if overlaid, since overlay construction

THICK = thickness of the AC layer most recently constructed

AADTK = (AGE)(AD)(THICK)

AD = weighted average surface deflection divided by ESWL (kips)

$$VCR = \sqrt{\sum_{i=1}^{a} (\sigma_v)(N)}$$

a = number of different aircraft

σ_v = stress on top of base course before most recent overlay

N = number of passes of aircraft before most recent overlay

$$AAV2 = (AGE)(AV)^2$$

AV = weighted average vertical stress on top of base course (psi)

A summary of the data used to develop Equation (4-4) is contained in Table 4-6.

The regression analysis entered the same variables, in the same order, into Equation (4-4), the modified improved model, as were entered in Equation (4-3), the improved model. However, the influence exerted by each variable on the PCI did change slightly. The variables [(PRECI)AGE)/THICK] and AADTK increased their influence on the PCI, while the variables [(AGE)(VCR)] and AAV2 lost some influence.

The coefficient of determination for the modified improved model increased to 0.86 for a total increase of 0.02 over the improved model (i.e., Equation (4-3)). The modified improved model has a coefficient of determination of 0.06 greater (i.e., 0.86 versus 0.80) than the original model, Equation (4-1), forced through the origin. This increase in the coefficient of determination equates to a 7.5 percent increase and would indicate that the modified improved model is the best predictor of the PCI in flexible pavement analyzed thus far.

Modified Improved Model Evaluation

A scattergram was run to compare the PCI values predicted by Equation (4-4) and the actual PCI for the 11 features at K.I. Sawyer AFB. The relationship between the actual versus the predicted PCIs is shown in Figure 4-3.

TABLE 4-6

Summary of the Data Used in Developing the Modified Improved PCI Prediction Model

Variable	Mean	Standard Deviation	Range
ACTPCI	73.284	16.364	31-100
AGE (years)	10.136	8.021	0-27
VCR	6,367,072	15,700,000	0-116,300,000
PRECI (inches)	26.938	13.951	3.8-52.1
THICK (inches)	2.673	1.204	0.8-6.0
ADAV	0.100	0.071	0-0.367
AGE x ADAV	1.250	1.618	0-7.711
AGE x VCR	11,610	17,977	0-75,493
PRAGET*	108.723	101.145	0-416.8
AADTK	0.040	0.051	0-0.227
AAV2	105,760	146,750	0-689,005

*PRAGET = (AGE)(PRECI)/THICK

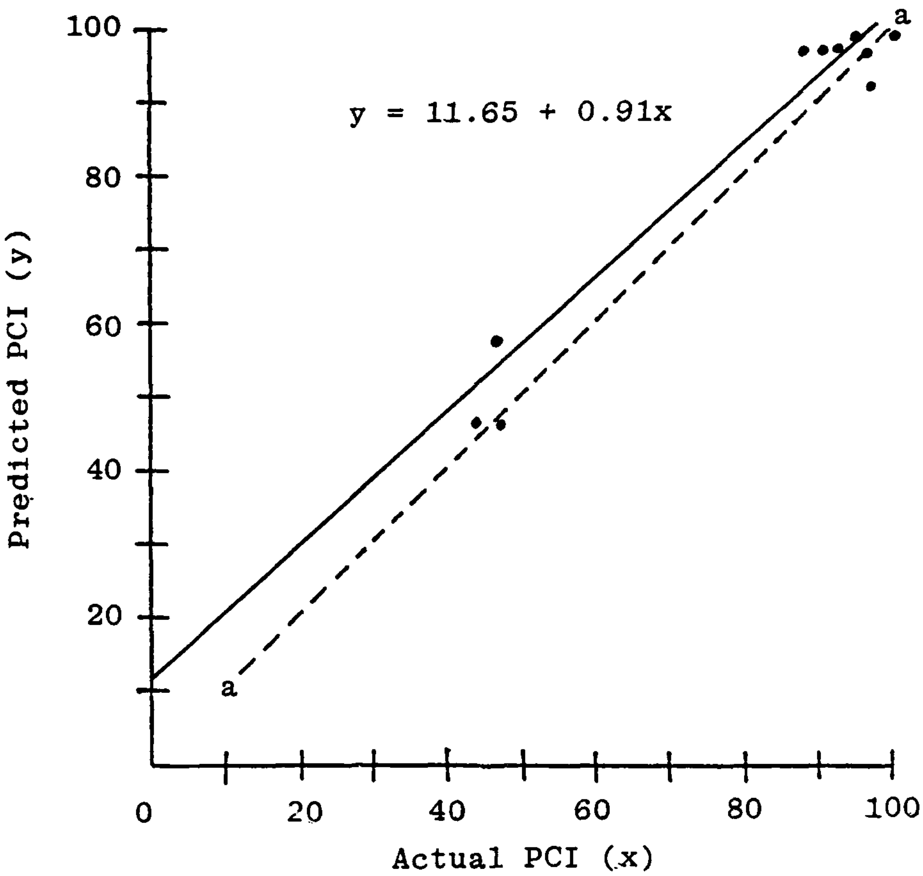


FIGURE 4-3

Scattergram of Actual versus Predicted PCI Values
for the Modified Improved PCI
Prediction Model

The best-fitting line plotted through the data comes the closest so far to line a-a, which indicates a perfect linear fit. The intercept decreased from 13.82 for the improved model to 11.65 for the modified improved model. An intercept of zero would indicate a perfect linear fit. The slope increased from 0.90 to 0.91, which is slightly closer to a perfect slope of 1.0. The intercept and slope for the original model forced through the origin (i.e., Equation (4-1)) were 20.15 and 0.74, respectively.

The Pearson's r for the modified improved model remained at 0.97, which indicates a continued very strong positive linear relationship between the actual and predicted PCI. The Pearson's r remained within 0.01 throughout all analyses.

It can be concluded from the analysis thus far that the modified improved model provides the best estimate of the PCI for the flexible airfield pavement features located at K.I. Sawyer AFB.

K.I. Sawyer AFB Model

It has been suggested by some of the engineers at CERL, that in order to be able to predict the PCI in airfield pavement with the greatest degree of accuracy, it may be necessary to develop a model for each Air Force base (4; 8). Data from the given base would be analyzed and a model usable only at that base would be developed. In order to explore

the possibilities of this suggestion, it was decided to analyze only the data from K.I. Sawyer AFB, to develop a model for predicting the PCIs in that base's flexible airfield pavements and then evaluate the model. Theoretically, this process should result in a very strong model (8).

To keep the analysis simple, it was decided to use only the variable combinations present in the original CERL model (i.e., Equation (2-7)). After forcing the regression (Ref Appendix H) through the origin and using only the data from K.I. Sawyer AFB, the following model was developed:

$$\text{PCI} = 100 + 0.0614(\text{PRECI})(\text{AGE})/\text{THICK} - 0.0008208(\text{AGE})(\text{VCR}) - 35.836(\text{AGE})(\text{ADAV}) \qquad (4\text{-}5)$$

where:

PCI = Pavement Condition Index at age and traffic since construction or overlay

PRECI = mean annual precipitation, inches

AGE = age of pavement since construction or, if overlaid, since overlay construction

THICK = thickness of the AC layer most recently constructed

$$\text{VCR} = \sqrt{\sum_{i=1}^{a} (\sigma_v)(N)}$$

a = number of different aircraft

σ_v = stress on top of base course before most recent overlay

N = number of passes of aircraft before most recent overlay

ADAV = AD x AV

AD = weighted average surface deflection divided by ESWL (kips)

AV = weighted average vertical stress on top of base course (psi)

A summary of the K.I. Sawyer AFB data used to develop this model was shown in Table 4-2.

Equation (4-5) is significantly different than the original model forced through the origin. All variables continued to be significant; however, the order in which they entered the equation and their coefficients were different. The variable [(AGE)(ADAV)] entered the equation last in this model, whereas it entered second in Equation (4-1). This means that [(AGE)(ADAV)] is the least significant of all the variables in predicting the PCI at K.I. Sawyer AFB. The coefficients of all the variables increased over those in Equation (4-1), which indicates that the influence of each variable over the PCI increased.

The adjusted coefficient of determination increased greatly, to 0.98. This indicates that almost all the variation in the PCI at K.I. Sawyer AFB is explained by the model (i.e., Equation (4-5)). This was expected, because only the data from K.I. Sawyer AFB was used to build the model.

Evaluation of the K.I. Sawyer AFB Model

The PCIs for the 11 features at K.I. Sawyer AFB were estimated using Equation (4-5) and were compared to the

actual PCIs using the SPSS SCATTERGRAM routine. The scattergram is shown in Figure 4-4. The slope was 0.99 which is very close to a perfect 1.0. The intercept of 2.28 was also very close to a perfect zero. The Pearson's r was 0.99, indicating a nearly perfect positive linear relationship and remaining very close to the values found in the other models evaluated in this research.

It can be concluded that Equation (4-5) is the best model presented in this analysis for predicting the PCI in the flexible airfield features of K.I. Sawyer AFB. However, the model is limited to use only at this base because of the data used to develop it.

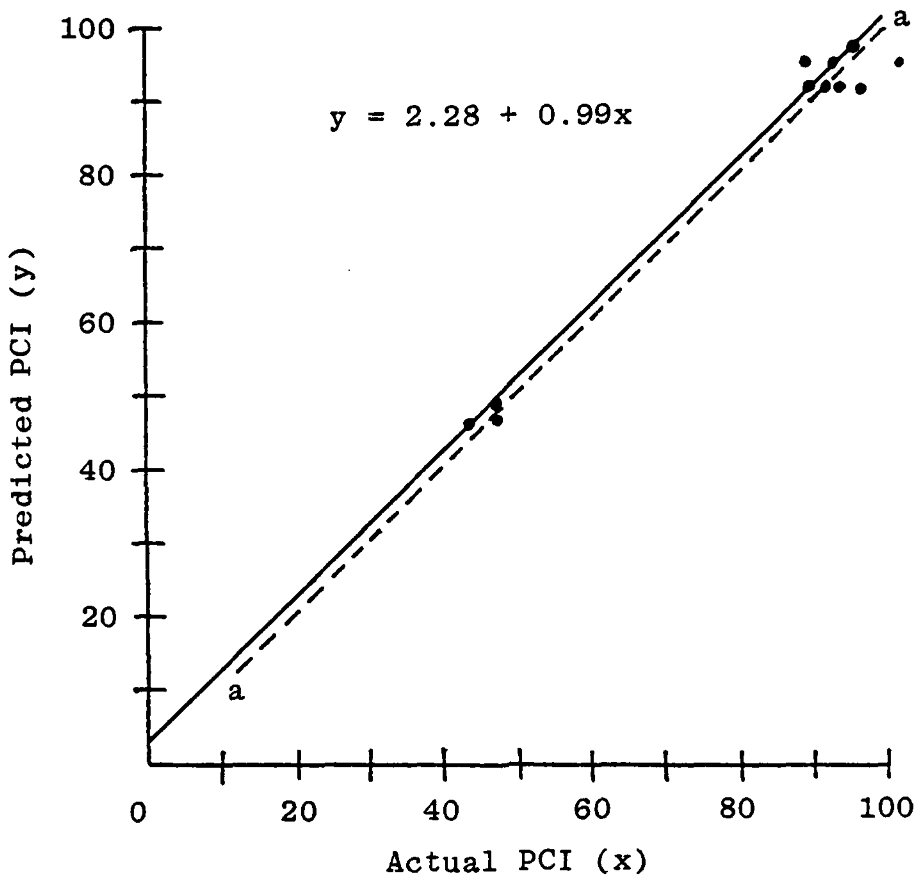


FIGURE 4-4

Scattergram of Actual Predicted PCI Values for the K.I. Sawyer AFB PCI Prediction Model

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research has been to evaluate the current U.S. Army Construction Engineering Research Laboratory (CERL) model for the prediction of the Pavement Condition Index (PCI) of flexible airfield pavements. A PCI prediction model is a necessary part of the pavement maintenance management system which CERL is developing at the request of the Air Force. Once a valid model is adopted, flexible pavement can be analyzed to see how it will react to various environmental and situational factors. Also, various maintenance and repair alternatives can be studied to determine cost effectiveness. With the ability to make cost effective decisions concerning pavement, follows the more effective use of the limited funds available for repairing and maintaining the Air Force's aging airfield pavements.

The overall objective of this thesis was to validate the PCI prediction model for flexible pavements. To meet this overall objective, four research questions were asked in Chapter 1. Each question will be restated and the conclusions discussed, followed by some recommendations for future research.

Research Question #1: Does the current model for flexible pavement reasonably predict pavement condition indices when applied to a new data base?

The analysis found that the original equation suggested by CERL for PCI prediction in flexible airfield pavements was based on a questionable statistical procedure. This questionable procedure involved the addition of 70 data features, with assumed PCIs of 100 and ages of zero, to the original 70 features. The additional data was not field collected, but entered based on the assumption that new pavement should rate a PCI of 100. The effect of the additional data was to dramatically increase the coefficient of determination and the regression constant. Rather than continue using a questionable technique, it was decided to reaccomplish the original model using only the 70 field surveyed data features and forcing the regression through the origin.

The original model, forced through the origin, was used to compute the predicted PCIs for the 11 features surveyed at K.I. Sawyer AFB. The predicted PCI values were then compared to the actual PCIs found in the survey. The comparison revealed that the original model for flexible pavement is a reasonable predictor of the PCI. However, the model was incapable of predicting the PCI without error. The model tended to underpredict the PCI for features in excellent condition. The best-fitting regression line

through the data plotted very close to the optimum linear regression line, as shown in Figure 5-1. Unfortunately, Figure 5-1 shows the model to be weakest in the area of most concern to those who make pavement maintenance and repair decisions; that is, in predicting the PCI in pavements in failed to poor condition. This means that significant errors in the prediction of the pavement condition would occur in the region where the model would most often be used, on pavements which have already begun to show deterioration.

Research Question #2: When new data are added to the existing field data, what is the effect on the PCI prediction model?

The new data collected at K.I. Sawyer AFB was added to the original data base and a regression analysis was performed. The independent variables all remained significant and entered the equation in the same order as in the original model. The coefficients of the independent variables did change slightly, thereby changing their individual influence on the PCI. The ability of the model to accurately predict the PCI in flexible airfield pavement improved, as indicated by an increase in the adjusted coefficient of determination from 0.80 in the original model to 0.82 in the modified model.

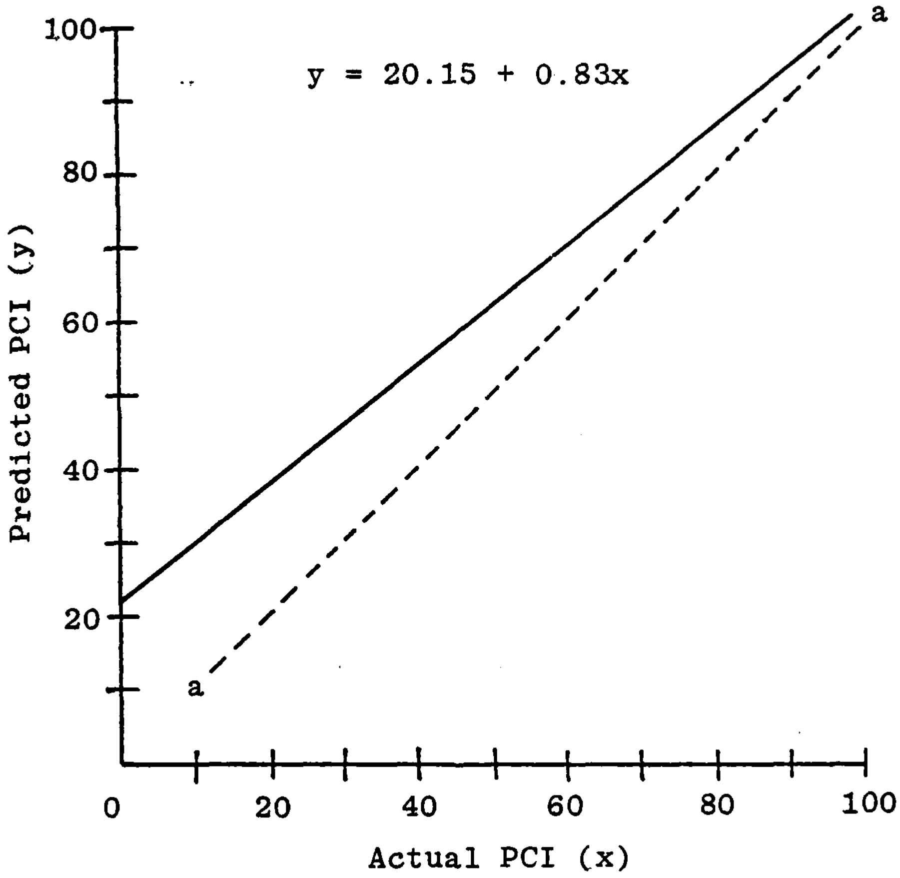


FIGURE 5-1

Scattergram of Actual versus Predicted PCI Values for the Original PCI Prediction Model Forced Through the Origin

Research Question #3: By using new and existing data, can the PCI prediction model for flexible pavement be improved upon?

Several new variables were analyzed to determine the affects of nonlinearity and interaction among the original variables. Also, attempts were made to use the new variables to improve the PCI prediction capability. The model that evolved contained four independent variables; two were variables from the original model, one was a new interactive variable, and the last was a nonlinear variable. These variables indicated that the relationship between the PCI and the independent variables is basically linear, with some interactive and nonlinear relationships present. More important is the fact that the predictive capability was improved, as indicated by an increase in the adjusted coefficient of determination from 0.80 in the original model to 0.84 in this model.

The K.I. Sawyer AFB data was added to the original data base and the regression analysis was rerun to determine the effect. The coefficients of the independent variables were adjusted slightly, but all variables remained significant. The predictive capability of the model was again shown to increase, as the adjusted coefficient of determination increased from 0.84 to 0.86. The total increase in the adjusted coefficient of determination over this study was 0.06 (from 0.80 to 0.86) or an increase of 7.5 percent.

Research Question #4: Can a model be built for a particular base, using only the data from that base, that improves the prediction of the PCI as compared to the general model?

At the suggestion of the engineers at the U.S. Army Construction Engineering Research Laboratory (CERL) it was decided to explore the possibility of developing a model for an individual base, using only data gathered at that base (4; 8). A regression analysis was run on the 11 data features collected at K.I. Sawyer AFB and a model developed which very accurately predicts the PCI for flexible features at that base. The adjusted coefficient of determination for the model was 0.98, which approaches the perfect 1.0 possible. The model is obviously the best available for predicting the PCI in flexible airfield pavement at K.I. Sawyer AFB, but is unusable at any other location because of the limited data used to develop it.

This thesis has achieved the purpose of evaluating the current PCI prediction model proposed for flexible airfield pavements. It was found that the original model was developed based on a nonstandard statistical practice. A more acceptable method resulted in a model that was still unable to predict, without unreasonable error, the PCIs in deteriorating pavement. For example, a pavement with a PCI of 40 would have a predicted PCI value of 53, which is a 33 percent error. The best general model analyzed, computes

the pavement with an actual PCI of 40 to be 48, which is more acceptable, but still in need of further improvement. The model applicable only at K.I. Sawyer AFB, predicts the PCI of the same features to be 42, or an acceptable five percent error. The problem with the K.I. Sawyer AFB model is that it is not usable anywhere but that base, and if this approach is followed, models would have to be developed for over 120 Air Force installations.

Recommendations

The models to predict the Pavement Condition Index for rigid and flexible pavements have been gradually improved since first introduced in 1979. Still, there are many areas which need to be studied before use of the models is made mandatory through Air Force Regulation. The following items are suggestions for further research on this subject.

1. The U.S. Army is already studying PCI prediction models based on nonlinear combinations of variables (4). The modified improved model (i.e., Equation (4-4)) presented in this thesis, was based on a limited number of variables, but proved that nonlinear combinations could be significant in PCI prediction. These models are still tentative. Efforts should be made to add to the data base to prove or disprove the validity of the nonlinear model being presented for the prediction of the PCI.

2. This research presented a model for the prediction of the PCI in flexible pavement only at K.I. Sawyer AFB (i.e., Equation (4-5)). Since the data used to build this model represents all the flexible airfield pavement on K.I. Sawyer AFB, the validity cannot immediately be tested. However, in three to five years, the pavement surveyed will have aged and some of the pavement that was in fair condition will have likely been overlaid or reconstructed. At that time, a study could be made to determine the validity of the model. Along with determining the validity, an economic analysis should be done to see if the additional accuracy available from a locally developed model is worth the extra time and effort required to develop one for each Air Force base.

3. In the development of the current PCI prediction model, the U.S. Army gathered data from the 12 bases shown in Figure 2-10. Most of these bases are located in the southern United States. The data gathered at K.I. Sawyer AFB had a large amount of polished aggregate as the result of extremely heavy snow removal operations. The present model has no means of accounting for polished aggregate and it is a possible problem at every northern base because of snow removal efforts. The lack of a variable to handle polished aggregate distresses could account for some of the error in the models presented in this study. Efforts should be made to gather additional data from middle and northern

U.S. bases, as well as overseas locations. Once this is done, a study could be made to determine if a model might more accurately predict the PCI for bases in the northern tier by the addition of a variable to account for the polished aggregate. Also, a study could be made to determine if a regional model might better predict the PCI of pavements in that region, than a general model. Models of this type might prove more accurate than the current general model, yet be less expensive to develop than a model for each base.

APPENDICES

APPENDIX A

PAVEMENT CONDITION INDEX CONDITION SURVEY SUMMARY FOR FLEXIBLE FEATURES AT K.I. SAWYER AFB

FEATURE 1

PCI OF FEATURE-RUNWAY 01 FIRST 1000 FT = 43   RATING = FAIR

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE RUNWAY 01 FIRST 1000 FT

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
01 ALLIG CRK	LOW	1757	3.51	32.7
01 ALLIG CRK	MEDIUM	200	0.40	21.0
06 JET BLAST		100	0.20	0.5
08 LONG & TRAN CRK	LOW	4415	8.83	21.3
08 LONG & TRAN CRK	MEDIUM	709	1.41	13.7
10 PATCH	LOW	100	0.20	2.0
10 PATCH	MEDIUM	250	0.50	8.0
11 POL AGG		25000	50.00	37.0

LOAD RELATED DISTRESSES = 43.09 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 29.36 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 27.53 PERCENT DEDUCT VALUES.

FEATURE 2

PCI OF FEATURE-RUNWAY 01, 2ND 4300 FT = 46   RATING = FAIR

RECOMMENDED MINIMUM OF 8 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED = 6.9

ESTIMATED DISTRESS FOR FEATURE RUNWAY 01, 2ND 4300 FT

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
01 ALLIG CRK	LOW	4510	2.09	27.4
01 ALLIG CRK	MEDIUM	1097	0.51	23.1
02 BLEEDING		2	0.00	0.0
08 LONG & TRAN CRK	LOW	19288	8.97	21.6
08 LONG & TRAN CRK	MEDIUM	5491	2.55	18.6
10 PATCH	LOW	43	0.02	0.4
10 PATCH	MEDIUM	40	0.01	0.6
11 POL AGG		107500	50.00	37.0

LOAD   RELATED DISTRESSES = 39.78 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 31.35 PERCENT DEDUCT VALUES.

OTHER   RELATED DISTRESSES = 28.86 PERCENT DEDUCT VALUES.

FEATURE 3

PCI OF FEATURE-TAXIWAY B = 90 RATING = EXCELLENT

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE TAXIWAY B

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
08 LONG & TRAN CRK	LOW	1685	2.75	9.5
09 OIL SPILL		106	0.17	2.0

LOAD RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 82.60 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 17.39 PERCENT DEDUCT VALUES.

FEATURE 4

PCI OF FEATURE-TAXIWAY C = 87   RATING = EXCELLENT

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE TAXIWAY C

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
08 LONG & TRAN CRK	LOW	992	1.75	7.2
09 OIL SPILL		4112	7.26	12.3
12 RAV/WEATH	MEDIUM	30	0.05	2.0

LOAD RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 42.79 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 57.20 PERCENT DEDUCT VALUES.

FEATURE 5

PCI OF FEATURE-TAXIWAY D = 91 RATING = EXCELLENT

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE TAXIWAY D

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
05 DEPRESSION	LOW	270	0.65	3.6
08 LONG & TRAN CRK	LOW	745	1.80	7.4
09 OIL SPILL		260	0.63	2.8

LOAD RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 53.62 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 46.37 PERCENT DEDUCT VALUES.

FEATURE 6

PCI OF FEATURE-TAC ALERT HANGER FRONT = 91

RATING = EXCELLENT

RECOMMENDED MINIMUM OF 5 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED = 2.7

ESTIMATED DISTRESS FOR FEATURE TAC ALERT HANGER FRONT

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
08 LONG & TRAN CRK	LOW	1899	2.72	9.4

LOAD RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 100.00 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

FEATURE 7

PCI OF FEATURE-TAC ALERT HANGER SIDE = 92

RATING = EXCELLENT

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE TAC ALERT HANGER SIDE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
05 DEPRESSION	LOW	78	0.35	1.7
08 LONG & TRAN CRK	LOW	426	1.95	7.8

LOAD RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 82.10 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 17.89 PERCENT DEDUCT VALUES.

FEATURE 8

PCI OF FEATURE-TAC ALERT HANGER BACK = 96

RATING = EXCELLENT

RECOMMENDED MINIMUM OF 5 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED = 3.7

ESTIMATED DISTRESS FOR FEATURE TAC ALERT HANGER BACK

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
08 LONG & TRAN CRK	LOW	122	0.45	3.7
09 OIL SPILL		96	0.35	2.1

LOAD RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 63.79 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 36.20 PERCENT DEDUCT VALUES.

FEATURE 9

PCI OF FEATURE-HUSHHOUSE TAXIWAY ON SRT = 94

RATING = EXCELLENT

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE HUSHHOUSE TAXIWAY ON SRT

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
08 LONG & TRAN CRK	LOW	126	0.85	4.9
09 OIL SPILL		25	0.16	2.0
10 PATCH	LOW	3	0.02	0.4

LOAD RELATED DISTRESSES = 2.73 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 69.86 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 27.39 PERCENT DEDUCT VALUES.

FEATURE 10

PCI OF FEATURE-HUSHHOUSE NEW TAXIWAY = 100

RATING = EXCELLENT

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE HUSHHOUSE NEW TAXIWAY

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE

LOAD RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

FEATURE 11

PCI OF FEATURE-HELOPAD = 46 RATING = FAIR

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE HELOPAD

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
01 ALLIG CRK	LOW	44	1.00	22.0
03 BLOCK CRK	MEDIUM	4550	100.00	55.0

LOAD RELATED DISTRESSES = 28.57 PERCENT DEDUCT VALUES.

CLIMATE/
DURABILITY RELATED DISTRESSES = 71.43 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

APPENDIX B

CONSTRUCTION ENGINEERING RESEARCH LABORATORY DATA

Actual PCI Value	Age	Traffic Passes (A)	Surface Deflection x 10^{-3} (D)	Vertical Stress, Current Period	Vertical Stress, Previous Period	Annual Precipitation	Thickness
46	11	805020	353.05	29198000	32184000	52.1	4.0
61	14	932700	754.92	141430000	0	52.1	4.0
84	12	467400	215.94	16628000	3553200	52.1	1.5
76	12	467410	215.94	16628000	3553200	52.1	1.5
39	26	164850	78.377	7775400	7101700	52.1	6.0
49	9	163000	393.72	19234000	0	49.6	3.0
73	9	38754	21.155	1286800	3229100	40.3	1.5
71	9	13380	18.211	1749100	2613400	40.3	1.5
74	9	13380	14.838	442400	526270	40.3	1.5
70	9	2678	2.97	88506	66100	40.3	1.5
74	9	13380	17.28	555850	656620	40.3	1.5
69	9	40140	49.936	4640000	8115700	40.3	2.0
99	1	3376	2.9138	270470	3360500	40.3	1.5
71	7	44625	39.762	4850100	18816000	40.3	2.5
79	8	2880	2.2306	163140	259690	40.3	1.5
84	5	302110	251.42	14807000	11241000	15.2	0.8
63	21	357000	352.76	48347000	0	15.2	4.0
86	14	84000	78.397	8650700	0	15.2	4.0
44	21	659860	1781.8	89729000	0	15.2	4.0
60	21	63441	66.992	9053000	0	15.2	4.0
100	0	1	0	0	7717900	15.2	1.0
100	0	1	0	0	2224800	15.2	1.0

```
73 19 9500 12.633 918650 0 15.2 5.0
95 3 6000 5.6196 701040 0 15.2 5.5
58 5 66135 73.213 5623400 22979000 10.6 1.5
67 4 52900 68.130 1252900 4159200 10.6 3.0
80 9 24408 25.532 1561900 2849400 10.6 2.0
92 2 4800 4.7443 147210 1008200 10.6 2.0
79 6 39000 49.226 5561200 7842200 10.6 1.0
31 24 393320 490.52 31592000 0 10.6 4.0
82 3 43590 44.252 2252400 17732000 10.6 2.0
72 7 18025 32.794 2117100 5098100 10.6 1.0
74 2 5150 4.3087 516760 5309900 10.6 2.0
86 6 6666 7.6456 321360 5339300 10.6 1.0
79 4 16880 23.374 663680 2069700 10.6 1.5
78 2 400 .36069 27640 107200 10.6 2.0
78 3 7725 8.2349 1352400 0 10.6 4.0
100 0 1 0 0 0 35.8 4.0
100 0 1 0 0 0 35.8 2.0
65 23 8436 8.7566 951350 0 35.8 4.0
74 8 90480 99.149 8844500 50036000 35.8 1.5
89 12 4425 4.4015 610020 0 35.8 4.0
51 27 12190 12.116 1947300 0 35.8 3.0
41 19 52431 50.441 8888500 0 35.8 4.0
58 14 52348 51.745 8363300 0 35.8 4.0
67 7 47747 42.647 2388600 14310000 35.8 3.0
71 7 469 .47663 43032 265450 35.8 2.0
82 7 469 .47663 43032 265450 35.8 2.0
65 7 69041 60.937 3598800 21946000 35.8 3.0
74 7 700 .74589 87046 512780 35.8 2.0
75 7 700 .74589 87046 512780 35.8 2.0
82 7 31619 28.757 1246900 7348600 35.8 3.0
48 7 36659 33.065 1569500 9521400 35.8 3.0
88 6 98616 63.355 2549700 8621500 11.5 1.5
89 6 98616 66.378 6182200 7101900 11.5 1.5
87 6 99216 64.705 3864300 4075600 11.5 1.5
79 6 98616 57.363 6202800 6109100 11.5 1.5
72 7 309440 393.65 38004000 53885000 3.8 1.5
60 7 309440 424.51 37158000 116310000 3.8 1.5
60 27 7200 7.731 869200 0 3.8 4.5
72 27 738800 1004.6 83002000 0 3.8 4.0
62 24 2400 3.1212 328550 0 3.8 4.0
71 6 30048 32.588 3144100 5822300 44.5 1.0
65 11 300300 688.76 11171000 0 27.2 4.0
70 12 49350 98.889 4469900 3918800 27.2 1.5
69 25 39600 89.996 4446500 0 27.2 3.0
72 25 90300 169.04 8880800 0 27.2 3.0
68 25 57300 118.51 5612200 0 27.2 3.0
53 25 20700 45.129 2036500 0 27.2 3.0
85 11 20900 45.534 794200 0 27.2 4.0
*EOR
```

APPENDIX C

K.I. SAWYER AFB DATA

Actual PCI Value

Age

Traffic Passes (A)

Surface Deflection x 10^{-3} (D)

Vertical Stress, Current Period

Vertical Stress, Previous Period

Annual Precipitation

Thickness

```
43 18 262320 215.68 8912900 10540000 32.9 3.5
46 18 262320 241.09 8230200 10602000 32.9 3.25
90 2 832 1.3165 67558 0 32.9 3.0
87 2 9356 12.804 446990 0 32.9 4.0
91 2 16244 21.049 823050 0 32.9 4.0
91 2 624 1.0967 47861 0 32.9 3.0
92 2 832 1.4622 63814 0 32.9 3.0
96 2 104 .18278 7976.8 0 32.9 3.0
94 1 2 .0024631 85.8 4314800 32.9 3.0
100 1 2 .0035149 153.4 0 32.9 3.0
46 21 13000 35.326 481000 0 32.9 2.0
*EOR
```

APPENDIX D

REACCOMPLISHMENT OF THE ORIGINAL PCI PREDICTION MODEL

```
RUN NAME        ORIGINAL MODEL FORCED THROUGH THE ORIGIN
VARIABLE LIST   ACTPCI AGE A D CVS VCR PRECI THICK
INPUT FORMAT    FREEFIELD
N OF CASES      UNKNOWN
COMPUTE         AD=D/A
COMPUTE         AV=CVS/A
COMPUTE         ADAV=AD*AV
COMPUTE         AGEADAV=AGE*ADAV
COMPUTE         AGEVCR=AGE*SQRT(VCR)
COMPUTE         PRAGET=PRECI*AGE/THICK
COMPUTE         PCI=ACTPCI-100
REGRESSION      METHOD = STEPWISE/VARIABLES = PCI,AGEADAV,
                AGEVCR,PRAGET/
                REGRESSION=PCI WITH AGEADAV,AGEVCR,PRAGET/
STATISTICS      ALL
OPTIONS         19
READ INPUT DATA

00052400 CM NEEDED FOR REGRESSION


OPTION - 1
IGNORE MISSING VALUE INDICATORS
(NO MISSING VALUES DEFINED...OPTION 1 WAS FORCED)

OPTION -19
FORCE REGRESSION THRU THE ORIGIN
```

```
0* * * * * * * * * * * * * * * * * * * * * * * * * M U L T I P L E   R E G R E S S I O N * * * * * * * * * * * * * * * * * * * * * * *
DEPENDENT VARIABLE..    PCI                                                                 ----- REGRESSION FORCED THROUGH ORIGIN ------

 VARIABLE(S) ENTERED ON STEP NUMBER   3..    AGEVCR

 MULTIPLE R            .89849        ANALYSIS OF VARIANCE     DF      SUM OF SQUARES       MEAN SQUARE          F      SIGNIFICANC
 R SQUARE              .80729        REGRESSION                3.       56193.90655        18731.30218       93.55811
 ADJUSTED R SQUARE     .80154        RESIDUAL                 67.       13414.09345          200.21035
 STD DEVIATION       14.14957        COEFF OF VARIABILITY     51.1 PCT

 TOTAL SUM OF SQUARES ADJUSTED FOR MEAN OF DEPENDENT VARIABLE
 MULTIPLE R  .89849        R SQUARE  .80729          ADJUSTED R SQUARE  .80154

 -------------------- VARIABLES IN THE EQUATION ---------------------          ---------- VARIABLES NOT IN THE EQUATION ----------

 VARIABLE          B           STD ERROR B           F             BETA          VARIABLE      PARTIAL    TOLERANCE        F
                                                ------------    ----------                                           ------------
                                                SIGNIFICANCE    ELASTICITY                                           SIGNIFICANCE

 PRAGET     -.56776945E-01   .15803179E-01    12.907886       -.2715300
                                                   .001          .23317
 AGEADAV    -7.5816834       .97234155        60.798604       -.5226358
                                                     0           .37764
 AGEVCR     -.55733328E-03   .94850347E-04    34.526464       -.3653710
                                                     0           .23593

 ALL VARIABLES ARE IN THE EQUATION.
```

APPENDIX E

DEVELOPMENT OF THE MODIFIED PCI PREDICTION MODEL

```
        RUN NAME         MODIFIED MODEL FORCED THROUGH THE ORIGIN
        VARIABLE LIST    ACTPCI AGE A D CVS VCR PRECI THICK
        INPUT FORMAT     FREEFIELD
        N OF CASES       UNKNOWN
        COMPUTE          AD=D/A
        COMPUTE          AV=CVS/A
        COMPUTE          ADAV=AD*AV
        COMPUTE          AGEADAV=AGE*ADAV
        COMPUTE          AGEVCR=AGE*SQRT(VCR)
        COMPUTE          PRAGET=PRECI*AGE/THICK
        COMPUTE          PCI=ACTPCI-100
        REGRESSION       METHOD = STEPWISE/VARIABLES = PCI,AGEADAV,
                         AGEVCR,PRAGET/
                         REGRESSION=PCI WITH AGEADAV,AGEVCR,PRAGET/
        STATISTICS       ALL
        OPTIONS          19
        READ INPUT DATA

00052400 CM NEEDED FOR REGRESSION


OPTION - 1
IGNORE MISSING VALUE INDICATORS
(NO MISSING VALUES DEFINED...OPTION 1 WAS FORCED)

OPTION -19.
FORCE REGRESSION THRU THE ORIGIN
```

```
* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * * * * * * * * * * * *
DEPENDENT VARIABLE..    PCI                                                              ----- REGRESSION FORCED THROUGH ORIGIN ------

 VARIABLE(S) ENTERED ON STEP NUMBER   3..    AGEVCR

 MULTIPLE R              .90633          ANALYSIS OF VARIANCE    DF       SUM OF SQUARES        MEAN SQUARE             F     SIGNIFICANC
 R SQUARE                .82143          REGRESSION               3.         65086.70961        21695.56987        119.59995
 ADJUSTED R SQUARE       .81685          RESIDUAL                78.         14149.29039          181.40116
 STD DEVIATION         13.46852          COEFF OF VARIABILITY    50.4 PCT

 TOTAL SUM OF SQUARES ADJUSTED FOR MEAN OF DEPENDENT VARIABLE
 MULTIPLE R  .90633         R SQUARE  .82143          ADJUSTED R SQUARE  .81685


 -------------------- VARIABLES IN THE EQUATION ----------------------          ---------- VARIABLES NOT IN THE EQUATION ----------

 VARIABLE            B             STD ERROR B          F            BETA           VARIABLE      PARTIAL     TOLERANCE        F
                                                  -------------  -----------                                              -----------
                                                  SIGNIFICANCE   ELASTICITY                                               SIGNIFICANCE

 PRAGET       -.62623258E-01   .14402366E-01   18.906172      -.2964720
                                                    .000         .25485
 AGEADAV      -7.4772693       .92259097       65.685218      -.4869780
                                                    .000         .34995
 AGEVCR       -.56784619E-03   .82126368E-04   47.807518      -.3868260
                                                    .000         .24676

 ALL VARIABLES ARE IN THE EQUATION.
```

APPENDIX F

DEVELOPMENT OF AN IMPROVED PCI PREDICTION MODEL

```
RUN NAME          IMPROVED MODEL
VARIABLE LIST     ACTPCI AGE A D CVS VCR PRECI THICK
INPUT FORMAT      FREEFIELD
N OF CASES        UNKNOWN
COMPUTE           AD=D/A
COMPUTE           AV=CVS/A
COMPUTE           AGEVCR=AGE*SQRT(VCR)
COMPUTE           PRAGET=PRECI*AGE/THICK
COMPUTE           AADTK=AGE*AD*THICK
COMPUTE           AAV2=AGE*(AV**2)
COMPUTE           PCI=ACTPCI-100
REGRESSION        METHOD = STEPWISE/VARIABLES = PCI,
                  AGEVCR,PRAGET,AADTK,AAV2/
                  REGRESSION=PCI WITH AGEVCR,PRAGET,
                  AADTK,AAV2/
STATISTICS        ALL
OPTIONS           19
READ INPUT DATA

00052400 CM NEEDED FOR REGRESSION

OPTION - 1
IGNORE MISSING VALUE INDICATORS
```

```
0* * * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * * * * * * * * * * * *
0DEPENDENT VARIABLE..     PCI
                                                                              ----- REGRESSION FORCED THROUGH ORIGIN ------
 VARIABLE(S) ENTERED ON STEP NUMBER   4..    AAV2
```

MULTIPLE R	.92190	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANC
R SQUARE	.84989	REGRESSION	4.	59159.30296	14789.82574	93.42107	.00
ADJUSTED R SQUARE	.84307	RESIDUAL	66.	10448.69704	158.31359		
STD DEVIATION	12.58227	COEFF OF VARIABILITY	45.4 PCT				

TOTAL SUM OF SQUARES ADJUSTED FOR MEAN OF DEPENDENT VARIABLE
MULTIPLE R .92190 R SQUARE .84989 ADJUSTED R SQUARE .84307

------------------- VARIABLES IN THE EQUATION ---------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
PRAGET	-.49215409E-01	.14041555E-01	12.284905	-.2353677
			.001	.20212
AADTK	-156.12857	38.630267	16.334631	-.3340843
			.000	.24035
AGEVCR	-.5706[illegible]0E-03	.84376979E-04	45.734304	-.3740797
			.000	.24156
AAV2	-.44982348E-04	.13700851E-04	10.779266	-.2763181
			.002	.19554

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

APPENDIX G

DEVELOPMENT OF A MODIFIED IMPROVED PCI PREDICTION MODEL

```
RUN NAME        MODIFIED IMPROVED MODEL
VARIABLE LIST   ACTPCI AGE A D CVS VCR PRECI THICK
INPUT FORMAT    FREEFIELD
N OF CASES      UNKNOWN
COMPUTE         AD=D/A
COMPUTE         AV=CVS/A
COMPUTE         AGEVCR=AGE*SQRT(VCR)
COMPUTE         PRAGET=PRECI*AGE/THICK
COMPUTE         AADTK=AGE*AD*THICK
COMPUTE         AAV2=AGE*(AV**2)
COMPUTE         PCI=ACTPCI-100
REGRESSION      METHOD = STEPWISE/VARIABLES = PCI,
                AGEVCR,PRAGET,AADTK,AAV2/
                REGRESSION=PCI WITH AGEVCR,PRAGET,
                AADTK,AAV2/
STATISTICS      ALL
OPTIONS         19
READ INPUT DATA

00052400 CM NEEDED FOR REGRESSION


OPTION - 1
IGNORE MISSING VALUE, INDICATORS
(NO MISSING VALUES DEFINED...OPTION 1 WAS FORCED)
```

0* M U L T I P L E   R E G R E S S I O N *

DEPENDENT VARIABLE..   PCI   ----- REGRESSION FORCED THROUGH ORIGIN ------

VARIABLE(S) ENTERED ON STEP NUMBER 4.. AAV2

MULTIPLE R	.92801	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANC
R SQUARE	.86121	REGRESSION	4.	68238.69831	17059.67458	119.44702	.00
ADJUSTED R SQUARE	.85580	RESIDUAL	77.	10997.30169	142.82210		
STD DEVIATION	11.95082	COEFF OF VARIABILITY	44.7 PCT				

TOTAL SUM OF SQUARES ADJUSTED FOR MEAN OF DEPENDENT VARIABLE
MULTIPLE R .92801   R SQUARE .86121   ADJUSTED R SQUARE .85580

-------------------- VARIABLES IN THE EQUATION --------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
PRAGET	-.54551882E-01	.12753652E-01	18.295755	-.2582604
			.000	.22200
AADTK	-172.15092	35.174831	23.952710	-.3555599
			.000	.26074
AGEVCR	.56493527E-03	.72727787E-04	60.338795	-.3848430
			0	.24549
AAV2	-.38531672E-04	.12316609E-04	9.7870861	-.2219418
			.002	.15253

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

APPENDIX H

DEVELOPMENT OF A LOCAL PCI PREDICTION MODEL FOR K.I. SAWYER AFB

```
RUN NAME        K.I. SAWYER AFB MODEL FORCED THROUGH THE ORIGIN
VARIABLE LIST   ACTPCI AGE A D CVS VCR PRECI THICK
INPUT FORMAT    FREEFIELD
N OF CASES      UNKNOWN
COMPUTE         AD=D/A
COMPUTE         AV=CVS/A
COMPUTE         ADAV=AD*AV
COMPUTE         AGEADAV=AGE*ADAV
COMPUTE         AGEVCR=AGE*SQRT(VCR)
COMPUTE         PRAGET=PRECI*AGE/THICK
COMPUTE         PCI=ACTPCI-100
REGRESSION      METHOD = STEPWISE/VARIABLES = PCI,AGEADAV,
                AGEVCR,PRAGET/
                REGRESSION=PCI WITH AGEADAV,AGEVCR,PRAGET/
STATISTICS      ALL
OPTIONS         19
READ INPUT DATA

00052400 CM NEEDED FOR REGRESSION


OPTION - 1
IGNORE MISSING VALUE INDICATORS
(NO MISSING VALUES DEFINED...OPTION 1 WAS FORCED)

OPTION -19
FORCE REGRESSION THRU THE ORIGIN
```

```
0* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * * * * * * * * * * * *
0DEPENDENT VARIABLE..    PCI                                                                ----- REGRESSION FORCED THROUGH ORIGIN ------

 VARIABLE(S) ENTERED ON STEP NUMBER   3..    AGEADAV

 MULTIPLE R              .99113        ANALYSIS OF VARIANCE     DF       SUM OF SQUARES        MEAN SQUARE           F       SIGNIFICANC
 R SQUARE                .98234        REGRESSION                3.          9457.95345         3152.65115       148.31944           .00
 ADJUSTED R SQUARE       .97792        RESIDUAL                  8.           170.04655           21.25582
 STD DEVIATION          4.61040        COEFF OF VARIABILITY     22.6 PCT

 TOTAL SUM OF SQUARES ADJUSTED FOR MEAN OF DEPENDENT VARIABLE
 MULTIPLE R  .99113        R SQUARE  .98234         ADJUSTED R SQUARE  .97792

 --------------------- VARIABLES IN THE EQUATION ----------------------       ---------- VARIABLES NOT IN THE EQUATION ----------
 VARIABLE             B           STD ERROR B          F            BETA         VARIABLE       PARTIAL    TOLERANCE        F
                                                  ------------   ----------                                             ------------
                                                  SIGNIFICANCE   ELASTICITY                                             SIGNIFICANCE

 PRAGET       .61438711E-01   .10400970          .34892855       .2684929
                                                      .571        -.23024
 AGEVCR      -.82082812E-03   .17850006E-03     21.145975       -.6925744
                                                      .002         .43652
 AGEADAV     -35.835581      16.590346           4.6657132      -.8423442
                                                      .063         .74371

 ALL VARIABLES ARE IN THE EQUATION.
```

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